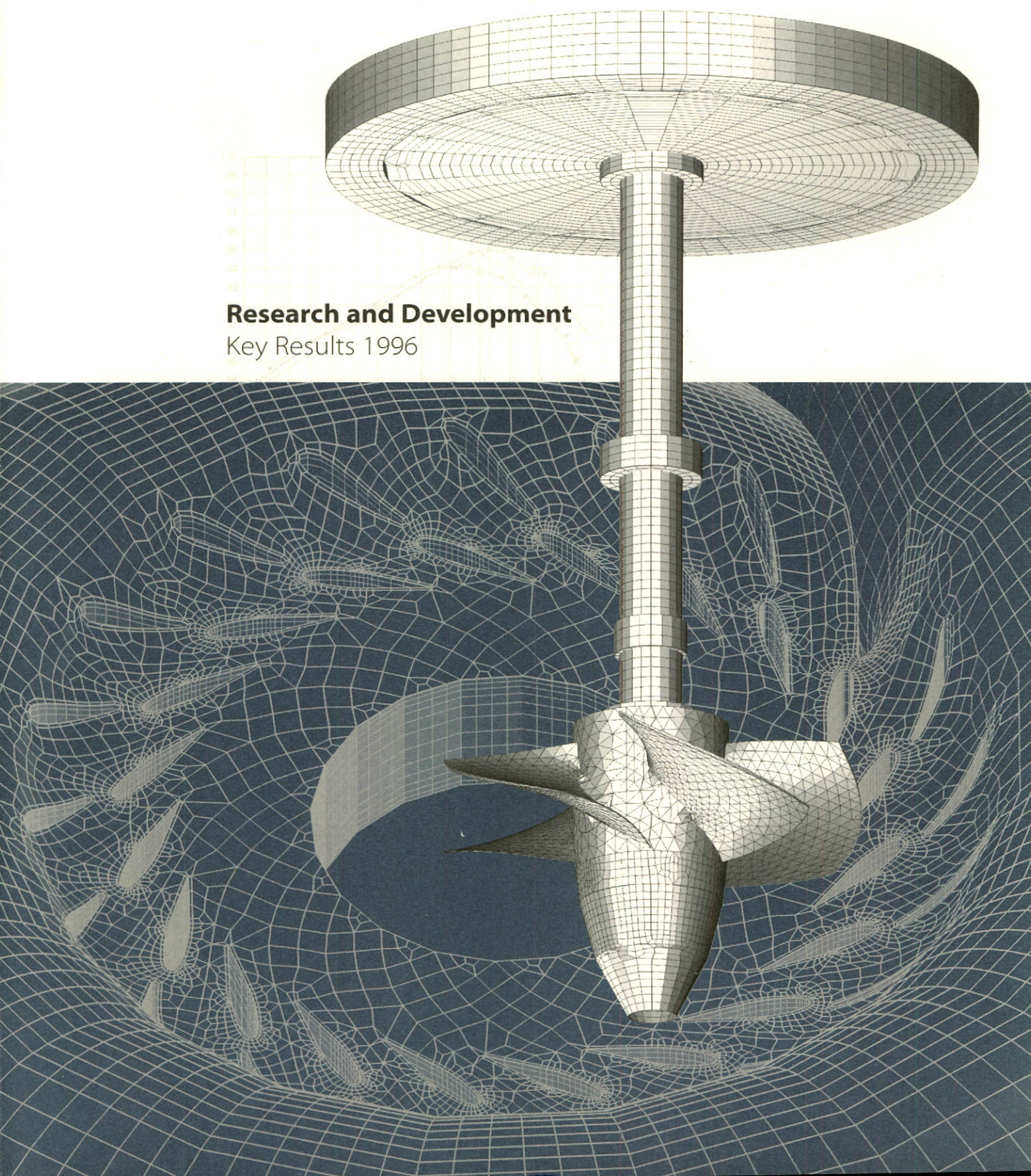
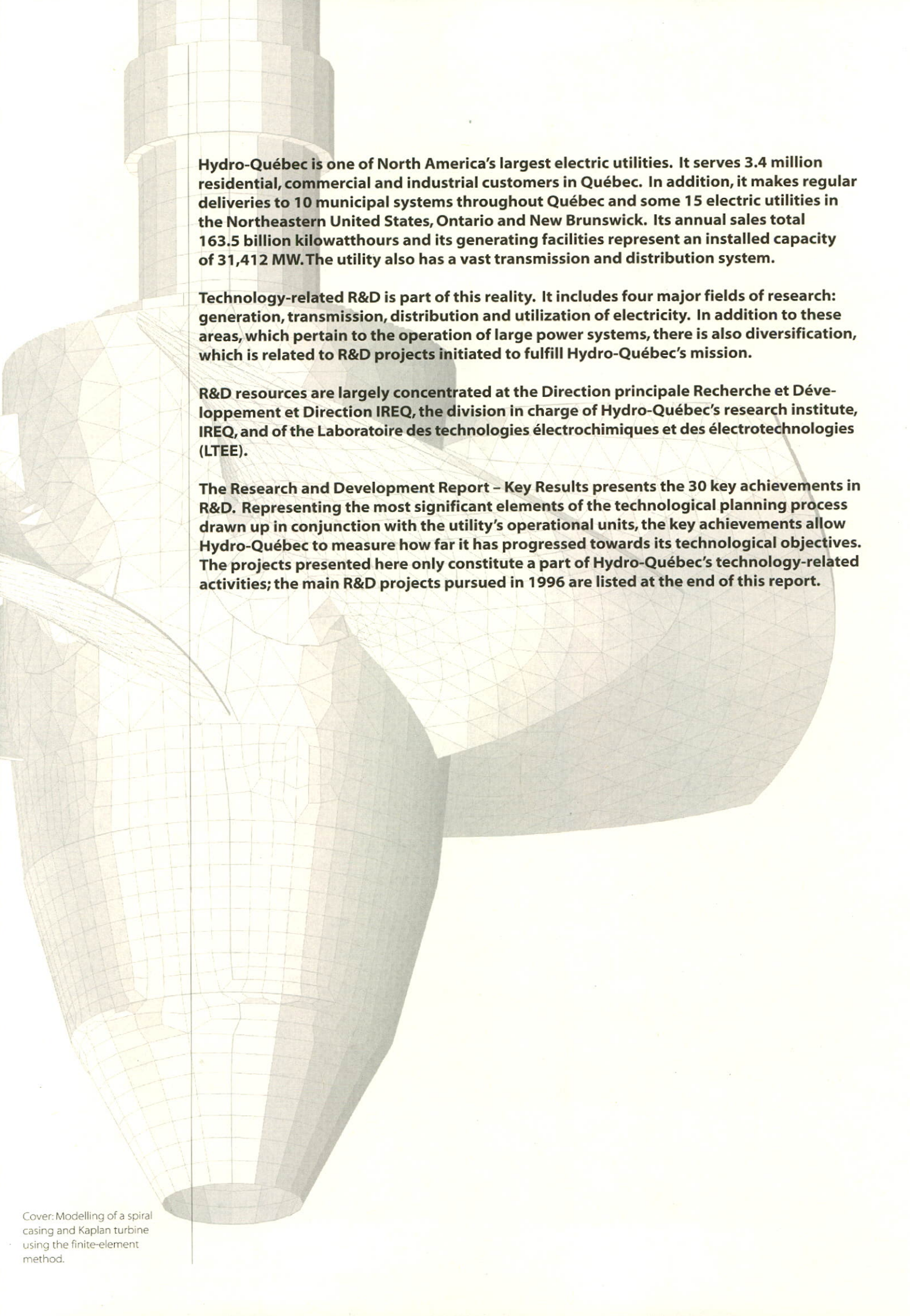


Research and Development
Key Results 1996





Hydro-Québec is one of North America's largest electric utilities. It serves 3.4 million residential, commercial and industrial customers in Québec. In addition, it makes regular deliveries to 10 municipal systems throughout Québec and some 15 electric utilities in the Northeastern United States, Ontario and New Brunswick. Its annual sales total 163.5 billion kilowatthours and its generating facilities represent an installed capacity of 31,412 MW. The utility also has a vast transmission and distribution system.

Technology-related R&D is part of this reality. It includes four major fields of research: generation, transmission, distribution and utilization of electricity. In addition to these areas, which pertain to the operation of large power systems, there is also diversification, which is related to R&D projects initiated to fulfill Hydro-Québec's mission.

R&D resources are largely concentrated at the Direction principale Recherche et Développement et Direction IREQ, the division in charge of Hydro-Québec's research institute, IREQ, and of the Laboratoire des technologies électrochimiques et des électrotechnologies (LTEE).

The Research and Development Report – Key Results presents the 30 key achievements in R&D. Representing the most significant elements of the technological planning process drawn up in conjunction with the utility's operational units, the key achievements allow Hydro-Québec to measure how far it has progressed towards its technological objectives. The projects presented here only constitute a part of Hydro-Québec's technology-related activities; the main R&D projects pursued in 1996 are listed at the end of this report.

Table of Contents

Foreword	4
Generation	6
Development of a hydraulic turbine analysis model (MATH)	6
GESVAR: Software for managing hydroelectric development options	7
SAGE: A new generation planning system	8
Controlling vibration in generating stator windings	8
Testing the resistance of semi-conducting paints used for stator windings	9
Study of corrosion in generating station water supply systems	10
New configuration for IREQ's tokamak device	11
New materials for reversible electrolysis	12
Transmission	13
Electrical endurance of high-voltage SF ₆ circuit breakers	13
Study of the performance of SF ₆ /CF ₄ gas mixtures used in HV circuit breakers	14
Optical amplifier shelter	15
Installation of optical ground wires using the cradle-block method	16
The icing rate meter: A device for measuring ice and its effects on power lines	17
Second version of data acquisition and control units	18
The ICOS system: Synchronous control interface for circuit breakers	18
EMTP software restructuring	19
ASTRE: Software for analyzing the stability of power system voltages	20
Distribution	21
Evaluation of protective coatings used for outdoor electrical distribution equipment	21
Development of a suspension insulator monitoring system	22

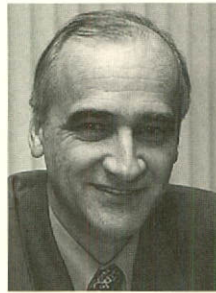
Table of Contents

Utilization	24
DROSCAR process	24
New applications for the induction-heated screw	25
Storage heaters and energy management	26
Commissioning and accreditation of VSD test bench	27
Training sessions and technical guide on electromagnetic compatibility	28
Study of the economic impact of harmonic disturbances	28
Test bench for HVAC technologies	29
Diversification	30
Polymer-electrolyte battery (ACEP) development project	30
Euro-Québec/Hydro-Hydrogen project	32
Development of a membrane separation process for the treatment of waste acid	33
Use of membrane separation for electrolyte purification	34
Appendix A	36
Other R & D projects (in 1996)	36
Appendix B	39
Organizational chart	39

Foreword

The opportunities presented by the deregulation of North American energy markets have led Hydro-Québec to undertake a major corporate restructuring and to question several of its practices. This is what brought the utility to implement a complete overhaul of its R&D activities in order to bridge the gap between its research and operations personnel. This shared responsibility of technological issues which Hydro-Québec has to face, both now and in the near to distant future, will help improve the utility's performance and increase its competitive edge.

Clearly aware of the major issues which its business units will have to face in a competitive environment, Hydro-Québec has chosen to at least maintain – if not increase – its R&D activities. The utility has very high expectations in this respect, since it is counting on research and development to help it maintain its technological leading edge in generation, transmission, distribution, and energy utilization.



In the future, efforts will be focused on renewable energy sources, i.e. not only hydroelectricity but also emerging technologies in generation and energy storage. We would like to explore the potential of new types of energy and identify the

most promising market niches. Our efforts will strengthen the utility's reputation in the area of renewable energy sources.

Moreover, as regards the utilization of electricity, our activities will be geared towards projects which target increased energy efficiency and the development of energy-efficient technologies.

Commercial concerns will be better integrated into the R&D process. To facilitate commercialization, a Product Development directorate has just been set up within the new Research and Development-IREQ division. Using a matrix-management approach, it will focus on marketing requirements at the very beginning of the R&D process and involve our industry partners in the development of technological products.

Hydro-Québec's
research institute, IREQ,
in Varennes



Foreword

The Laboratoire des technologies électrochimiques et des électrotechnologies (LTEE) in Shawinigan.

In 1996, some \$134 million was allotted to R&D, which represents 1.7% of our revenues, in addition to resources totalling 818 person-years. Of this amount, \$93 million was invested directly into research and development and \$22 million went to support activities, with \$19 million in revenues brought in.

R&D expenses are broken down by technological sector as follows: generation – \$16 million; transmission and communications – \$19 million; distribution – \$10 million; and energy efficiency – \$14 million. There are also the expenses related to development and commercialization (\$19 million), which cover projects such as ACEP and M4, as well as those related to research on new applications such as telerobotics, advanced materials, superconductivity and nuclear fusion (\$15 million). In terms of R&D spinoffs, a total of \$1.3 million was obtained from licensing agreements and \$13 million from sales of licensed products. Moreover, 2,430 jobs were supported, i.e. 818 at Hydro-Québec, 663 at our suppliers and 951 at Nouveler (including subsidiaries, affiliated technological companies and incubator firms).

A review of our partnerships in 1996 shows 136 separate projects involving 173 partners and 285 partnership agreements. Hydro-Québec invested \$16 million in these projects, with its partners' share representing \$38 million. Industrial firms account for a large proportion of these partnerships and roughly two-thirds of the investment (75 partnerships and \$24 million, respectively).

At the present time, 63% of our R&D efforts are realized based on a medium-term horizon – three years – and are aimed at meeting the needs of the business units (Generation, Transmission, Distribution, Customer Services and Energy Services). Long-term projects and prospective research, for their part, account for 18% of R&D spending.



The new management team is conscious of the efforts that must be expended to meet the new challenges in R&D. It knows it can count on the expertise of its personnel and especially on the know-how handed down by its predecessors. Therefore, I would like to take this opportunity to pay tribute to them. The R&D management team, which was headed by Louis Masson (who, until last November, was Vice President of the Technology and IREQ division), has strived to ensure a successful transition towards the next step in research and development and, in so doing, bring its activities in line with Hydro-Québec's changing face.

A handwritten signature in dark ink, reading "Roger Bérubé". The signature is fluid and cursive, with the first name "Roger" and last name "Bérubé" clearly distinguishable.

Roger Bérubé
General Manager
Research and Development
and Director IREQ

Generation

As hydroelectricity is Hydro-Québec's primary means of generation, it is natural that the utility should focus its efforts on increasing its knowledge of the operating parameters and developing management and analysis tools related to generating equipment.

The MATH hydraulic turbine analysis model allows the utility to study the behaviour of hydraulic turbines and to assess their efficiency. GESVAR, a software program for managing hydroelectric development options, is used to carry out hydroelectric development draft design studies according to a number of options in order to choose the optimal configurations from a technical and economic perspective. Lastly, the yearly generation planning system known as SAGE was developed to ensure optimal operation of hydroelectric resources.

Researchers have also been working on developing a method for monitoring and interpreting the main parameters related to the condition of generating units, and studying coating materials for stator windings and corrosion in generating station water supply systems.

In the area of emerging technologies, the utility has been pursuing its efforts in the field of fusion research, with a focus on the operation of the TdeV tokamak device, which was substantially modified in 1996. Other areas of research include reversible electrolysis, a technology that integrates water-based production of hydrogen in equipment which also generates electricity from hydrogen in order to make this technology economically feasible.

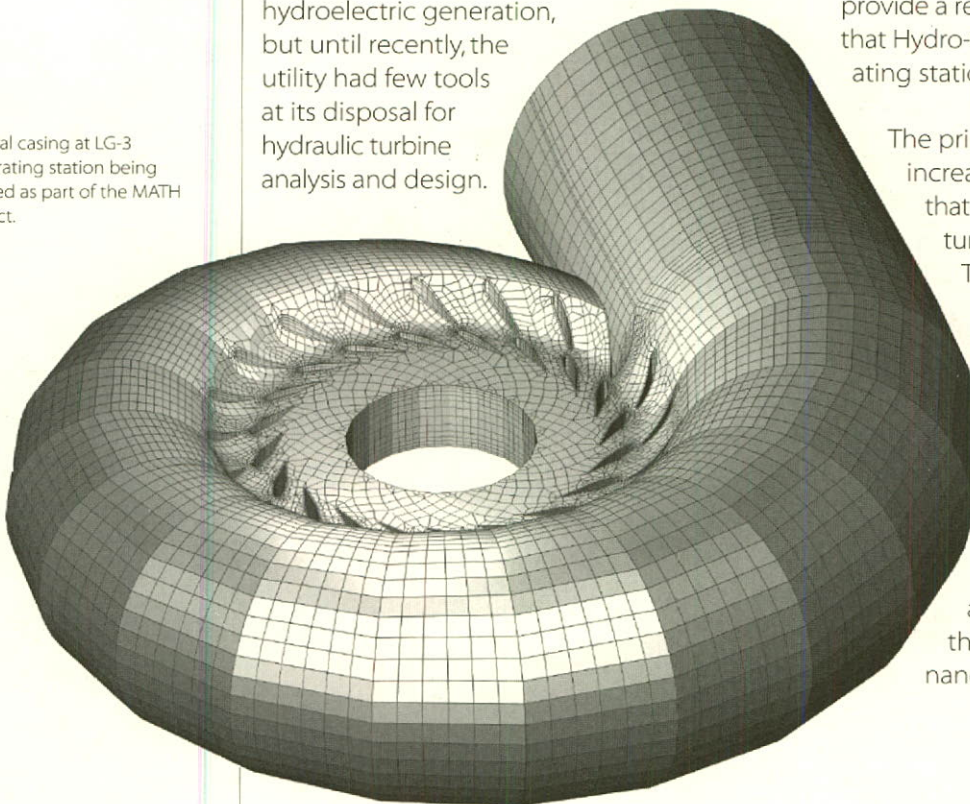
Development of a hydraulic turbine analysis model (MATH)

For several years now, Hydro-Québec has been placing prime importance on hydroelectric generation, but until recently, the utility had few tools at its disposal for hydraulic turbine analysis and design.

The development of the MATH project ("Modèles d'analyse des turbines hydrauliques" – Hydraulic turbine analysis models) met this need. This numerical modeling and simulation tool, which improves turbine performance, will provide a return on the substantial investments that Hydro-Québec intends to make in generating station rehabilitation and maintenance.

The primary aim of the MATH project is to increase knowledge of the parameters that influence the behaviour of hydraulic turbines and their related equipment. The model is thus used to simulate the fluid flow, frequencies and modes of vibration of a turbine runner, the geometry and mechanical characteristics of the runners, as well as assess turbine fatigue and efficiency. These data may then be used to validate the design of hydraulic equipment that is more resistant and better suited to each situation, thus potentially reducing maintenance costs.

A spiral casing at LG-3 generating station being studied as part of the MATH project.



In 1996, considerable progress was made on the MATH project. Regarding flow analysis, for instance, much more detailed data are now obtained thanks to highly precise geometric turbine modeling. Similarly, flow calculations performed in some hydraulic passages of LG-3 turbines pointed to reasons why the generating station's output was inadequate. Lastly, hydraulic pressure sensors were installed and calibrated on a Kaplan turbine as part of a joint project with GE-Hydro.

The MATH project was carried out jointly by members of two mechanical engineering departments (from IREQ and Hydro-Québec) and GE-Hydro, at the request of the utility's engineering and services division.

In 1997 the project team intends to conduct tests on the Kaplan runner, continue studying the performance of LG-3 turbines, and assess the operating risks related to high vibration zones in LG-2 generating units.

GESVAR: Software for managing hydroelectric development options

Hydroelectric development draft design studies require that several options be evaluated so that the optimal configurations are chosen to ensure success both from a technical and economic perspective. These studies are currently being carried out manually, using a repetitive process with many shortcomings, especially with respect to the limited number of options being considered, the inconsistent comparison of these variants, and the inaccuracy of cost estimates.

It thus became necessary, given the context of downsizing and cost reduction, to develop an efficient management tool for evaluating these options and selecting the best possible configurations. To this end, the GESVAR software program ("GEStionnaire de VARiantes" – Option management system) was developed; it allows studies and calculations to be done by computer, thus ensuring greater diversity in the options being studied, greater consistency in the comparative analysis, and greater accuracy in the calculations. GESVAR also includes calculation modules which help the designer to quickly analyze the various components (e.g. water intakes, penstocks, run-of-river installations, etc.) of each option while taking into account the civil, hydraulic, mechanical, geomatic and financial facets of the development project.

Considerable strides were made in the GESVAR project in 1996. For instance, development of the calculation modules of several components (e.g. tailbay, penstocks, water intake, independent multilayer topography) has almost been completed, the communication system linking the manager to the modules is operational, and nearly half of the cost-estimate module has been completed. Lastly, the software underwent validation testing at Hydro-Québec's LA-1 generating station and during construction of the Nam Khan II hydroelectric development in Laos, as per the contracts signed with Hydro-Québec International.

The GESVAR project was carried out jointly with the utility's generating facilities department and the firm RSW, at the request of the facilities division. The final version of the software should be delivered in 1997.

SAGE: A new generation planning system

Hydroelectric generation planning at Hydro-Québec involves use of an extensive process primarily occurring at three levels: long term or multi-annual; medium term or annual; short term or operational. It was within this context that a new computerized system – SAGE ("Système Annuel de Gestion de l'Énergie" – Yearly generation planning system) – was developed with the aim of improving yearly generation planning by reinforcing the utility's policy on reservoir management and generating station operation.

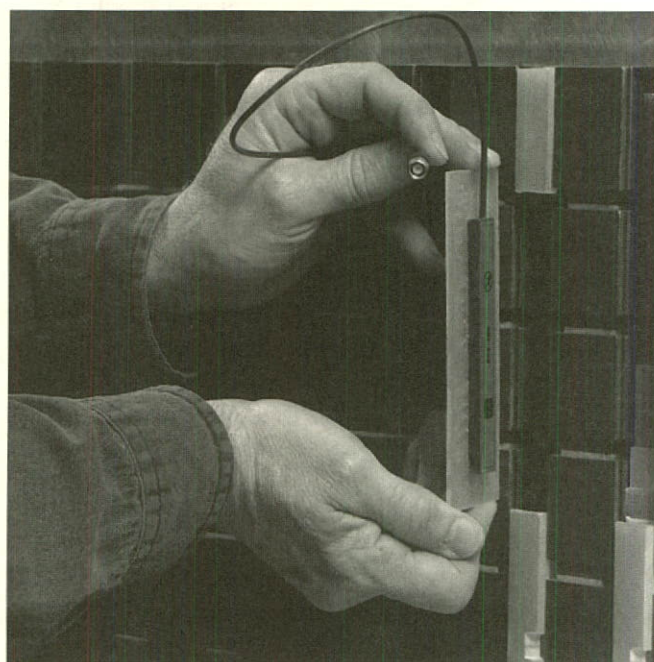
SAGE replaces the former NUMA III system which was used for reservoir management. More flexible and user-friendly than NUMA, SAGE has the added advantage of not being tied to a specific computing platform. In addition, it allows the planner to quickly respond to various issues that had not been anticipated at the time the system was designed without having to carry out major programming work. For instance, the system could be modified to take into account a potential increase in sales generated by deregulation in the U.S. electrical industry. It thus allows the planner to respond more precisely to issues related to the operation of hydroelectric facilities.

This was the first time that such a system was developed at Hydro-Québec using high-level optimization (i.e. CPLEX and MINOS software) and modelling tools (AMPL language). Researchers were thus able to concentrate on the modelling of generation planning rather than traditional computer programming.

The process of implementing SAGE was begun in January 1997 and tests conducted to date indicate that the new software will be a substantial improvement over the previous system. Development of the system led to many exchanges of technical expertise between the developers of the AMPL modelling language and IREQ's power system software specialists, who worked jointly on the project.

Controlling vibration in generator stator windings

For a number of years, Hydro-Québec has been working on increasing the availability of its generating units, a situation which largely depends on preventive and conditional maintenance. However, to optimize maintenance interventions, the main parameters related to the condition of the units must be carefully monitored. This work must also be done without shutting down the generator.



The wedging of stator windings is a key parameter since vibrations may occur as a result of loosening. Over time, such vibrations may lead to material setting and wear, which favours slot discharges. This may eventually cause a breakdown between the high-voltage winding and the magnetic core.

As it was impossible to check the wedging without shutting down the generating unit, we developed a contact-free capacitive measurement system to monitor vibration in the windings. The system was capable of immediately detecting any excessive shifting and to adapt maintenance interventions in time. Vibro-SystM, a Hydro-Québec subsidiary, is in charge of marketing the system.

Measuring system used to detect vibration in stator windings installed in the wedging slot of a laboratory model.

With each maintenance intervention, Hydro-Québec has been sporadically installing sensors for the past four or five years. Although certain permanent measuring systems have integrated this measurement, sensor recordings are not included in any monitoring program.

In 1996, new sensors were installed in the Manicouagan region in order to gather the data required for designing a method to monitor and interpret measurements. However, the main difficulty lies in finding ways of solving problems related to the loosening of the wedging. This is why several sensors were installed on the same unit but with different levels of slot wedging. The aim was to simulate various degrees of deterioration; however, startup problems with the target unit delayed the project.

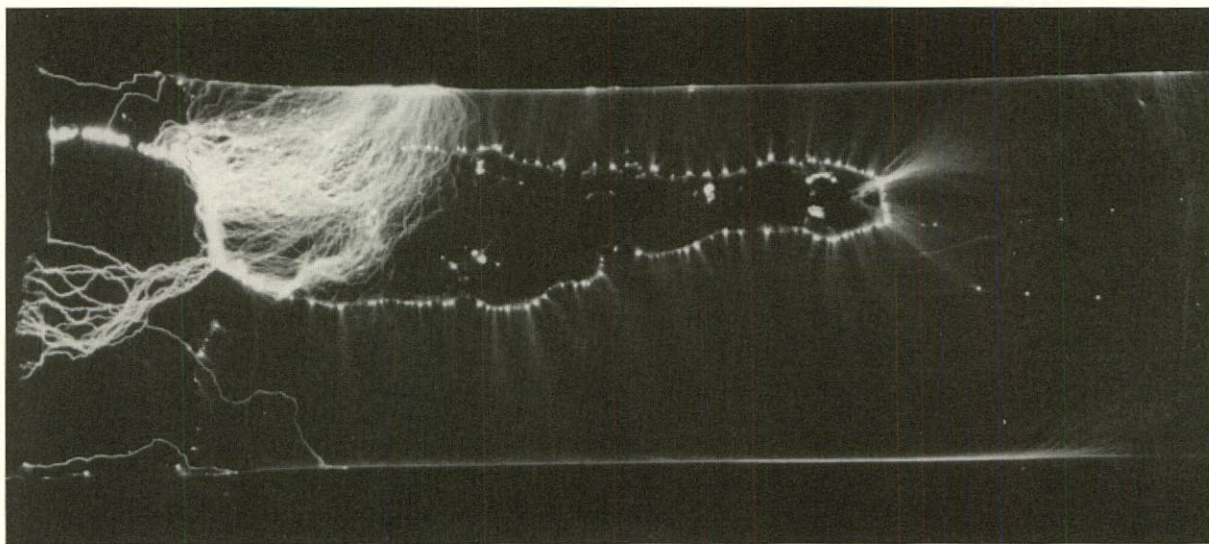
As a final note, it should be mentioned that the technology received international recognition in 1996, with utilities and organizations such as Manitoba Hydro, the U.S. Army Corps of Engineers, EDF, Duke Power and CEMIG in Brazil implementing the system and developing interpretation and monitoring programs. Manufacturers such as GE Canada and GE USA have also shown considerable interest in the technology.

Testing the resistance of semi-conducting paints used for stator windings

The semi-conducting paints used on generator stator windings are an integral part of their electrical insulation. As Hydro-Québec owns a large number of generating units, it is critical for the utility to know the effectiveness of this insulation, the extent of the damage incurred by stator windings and, especially, be able to forecast their residual life.

At the present time, the main insulating material used on stator windings provides the equipment with a useful service life of 40 years. However, in order to obtain this degree of reliability over the long term, the semi-conducting coating applied to the windings needs to be of high quality, for if the integrity of this coating is affected, very intense discharges may occur which eventually have a major impact on the winding's service life.

Partial discharges on alternator busbars.



Sample corrosion deposit in a carbon-steel pipe part of the water supply system.

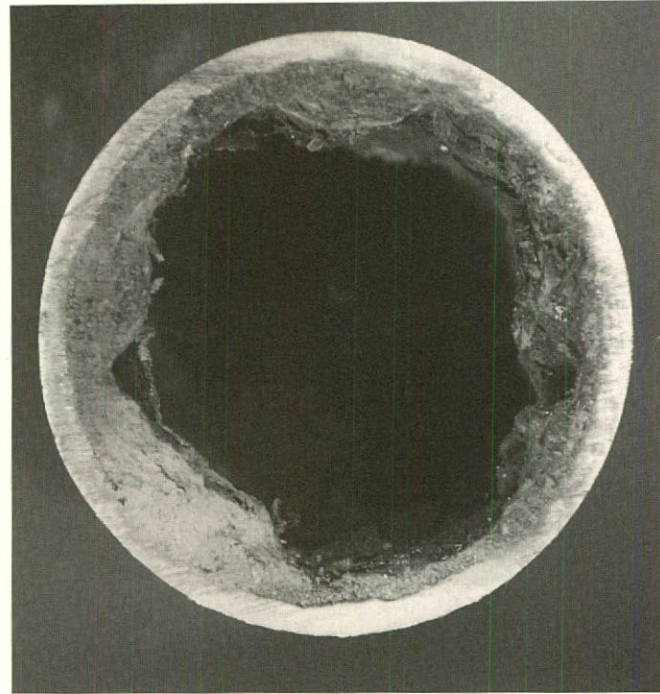
A project was therefore set up to demonstrate that the residual life of such equipment may be calculated with sufficient accuracy by assessing the condition of the paint on the windings. The project consisted of performing laboratory tests on the resistance of the stator windings to which poor-quality paint had been intentionally applied. The project team had to develop a new technique for measuring resistance – which, incidentally, is an interesting alternative to conventional techniques – as well as a measurement prototype. This work led to a number of improvements being made, which in turn allowed researchers to conduct a second series of tests on unit 42 at Outardes 4 generating station.

The project was carried out by IREQ's cables and insulation specialists at the request of the Manicouagan sector. In 1997, researchers intend to draw up recommendations based on the conclusions drawn from the two series of tests.

Study of corrosion in generating station water supply systems

Corrosion affects all the water supply systems in a hydroelectric generating station to some extent. As these systems are responsible for cooling the electrical apparatus in the powerhouse as well as for fire protection, any malfunctions may have serious consequences. It is thus vital to quantify the corrosion observed on generating station pipes so that the necessary corrective measures may be taken.

To this end, a project was initiated with a view to quantifying, qualifying and eventually controlling the corrosion on carbon-steel pipes found in generating station water supply systems. Researchers also sought to forecast the behaviour of 304 stainless steel using the electrochemical noise method. The project also served to determine the mechanical properties of PVC, both initially and after a certain interval of time, in order to measure the effects of the material's exposure to the electromagnetic environment of a generator shaft.



The results presented in a progress report in March 1996 revealed several important points. First, the corrosion on the carbon-steel pipes ranges from slight to moderate as per the criteria established by the National Association of Corrosion Engineers (NACE). The report concluded that mild steel is a material that is relatively well suited to our generating stations. However, the data did not clearly establish whether conditions characterized by the highest level of corrosion were associated with stagnant or running water, but they did reveal higher levels of corrosion on smaller-diameter pipes. Lastly, researchers measured electrochemical noise on test specimens of 304 steel installed in a water supply system at Beauharnois generating station and calculated the mechanical strength of a PVC specimen in the initial state.

Generation

The project, carried out at the request of the expertise and generation technical support division, was realized jointly by an IREQ research team, representatives from the Manicouagan and Maisonneuve sectors, and the firm Corrosion Management Ltd. The final report on the study of stainless steel and PVC will be submitted in 1997.

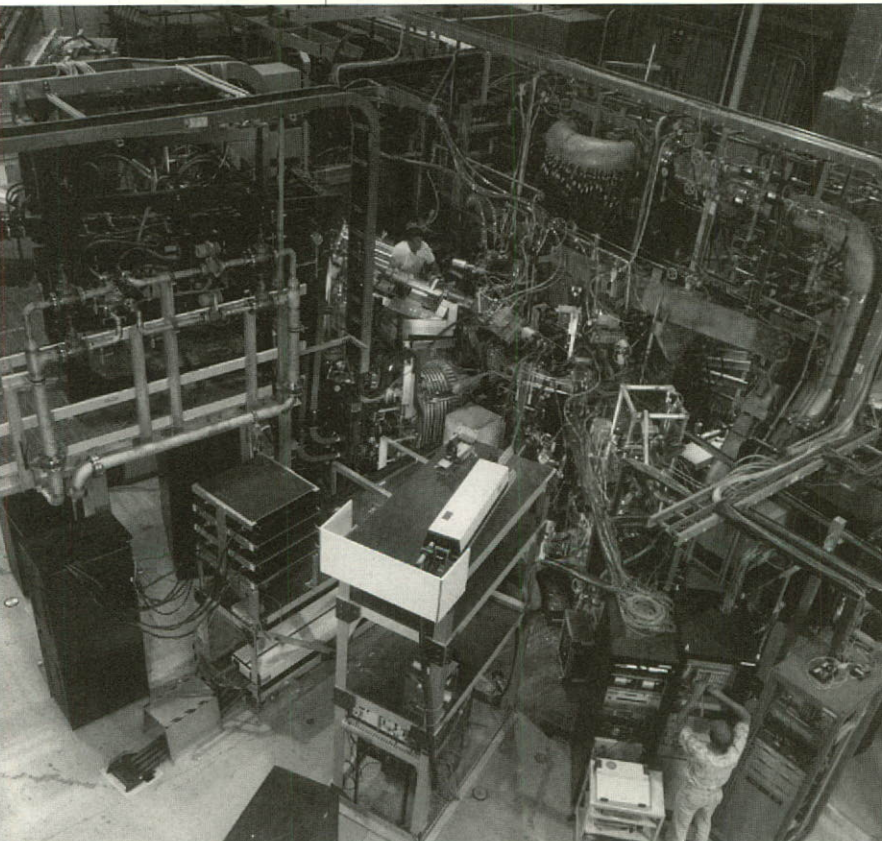
New configuration for IREQ's tokamak device

Hydro-Québec is involved in fusion research through the Centre canadien de fusion magnétique (CCFM), which has the mandate of operating the TdeV tokamak device. In the summer of 1996, a new configuration was implemented for the tokamak, now known as TdeV-96.

- Modifications made to the tokamak since the fall of 1995 include improvements to the magnetic divertors and major changes to the electrical systems. As the state-of-the-art divertor integrates the latest developments in the field, the TdeV is now more versatile with respect to the detailed assessment of various divertor operating modes. Hence, variations in the magnetic configuration of the divertor can now be better controlled so as to optimize the performance of this key component of future fusion reactors, especially regarding the extraction of the "ash" (helium) produced by the fusion reaction. Initial tests have confirmed the highly sophisticated design of the divertor, with a more in-depth assessment to take place in 1997.

The new magnetic configuration is based on an increase in the number of magnetic field coils which use independent power supplies. To obtain these independent sources, two of the existing sources have been split into separate parts and two more power supplies have been added. These modifications have required a much more sophisticated approach for the plasma control system in the tokamak. It should be pointed out that the overall control system of the experimental installation was also substantially refurbished.

View of the tokamak
de Varennes (TdeV)



The addition of new sources of power supply has in turn required major changes aimed at improving the power factor of the load on the power system. Fourteen 3.3-MVAR capacitor banks were installed, each of which will be switched by vacuum contactors as the toroidal magnetic field increases. By increasing the power factor from 0.7 to 0.9, the tokamak may be operated at its maximum magnetic field of 2 teslas as well as with high-frequency heating and current-drive systems.

Regarding the high-frequency systems, installation of the electron cyclotron heating system is progressing at a satisfactory pace. The base infrastructure for the gyrotrons has now been completed as has that of the tetrodes, which allow the gyrotrons and existing klystrons to be operated from the same electrical supply. Operation of TdeV with 20 MW of auxiliary heating is slated to begin in 1997.

Lastly, in October 1996, the CCFM hosted the 16th Conference on Fusion Energy Research sponsored by the International Atomic Energy Agency. Some 600 delegates from 40 countries took part in the week-long conference in Montréal. The event was a resounding success, with 300 of the delegates coming to IREQ to visit the tokamak installation.

New materials for reversible electrolysis

Over the past few years, Hydro-Québec has been studying the possibility of using hydrogen as a means of storing electricity on a large scale. More specifically, the utility has been looking into ways of integrating water-based production of hydrogen in equipment which would also generate electricity using hydrogen, thereby making this technological option economically feasible.

Researchers found that solid oxide fuel cells (SOFC) seem to meet these requirements. However, this technology requires materials with very specific characteristics, being both stable and highly resistant. In fact, the fuel cells operate at very high temperatures (1000°C) and use reversible electrolysis, which requires materials that are resistant to oxidizing and reducing agents.

Hydro-Québec thus decided to develop and characterize electrode materials that could be incorporated into these electrochemical fuel cells. Work focused on the synthesis and physico-chemical and morphological characterization of various perovskite-type compounds in ABO₃ form ("A" consisting of lanthanum with or without strontium, "B" of cobalt or manganese, and "O" of oxygen).

Begun in April 1994, these activities allowed researchers to determine the stability field of electrode materials (cobaltites and strontium manganites) used in SOFCs. They also revealed the importance of the perovskite cation A/B ratio for solving problems related to the shaping of the compounds being studied. Lastly, new perovskite compounds were synthesized (cobalt manganite and lanthanum ferrite) and the ionic conductivity of lanthanum manganite was studied.

This long-term research project was cofunded by the Hydrogen Industry Council of Canada, in addition to benefitting from the scientific contribution of Bourgogne University in Dijon, France and the Solids Reactivity Laboratory (Laboratoire de la réactivité des solides) of the National Scientific Research Centre (CNRS), also in France.

Transmission

Hydro-Québec is continuing to study ways of improving its high-voltage transmission system, which is internationally recognized. For instance, it has worked on improving circuit breakers by studying electrical endurance, insulating gas mixtures, and the interfaces used in the command chain.

In the area of fibre-optic communications, the utility has tested optical amplifier shelters – intermediate sites used to link remote substations – and developed a method for installing optical ground wires on high-voltage lines. Researchers have also developed a second-generation icing rate meter for monitoring ice conditions in real time, as well as a new and less expensive version of the data acquisition and control units used in generating stations and substations.

Hydro-Québec and international partners have worked on restructuring the EMTP software used to reproduce transient phenomena that occur on transmission and distribution systems. In the current context of deregulation, the software could also be used to produce highly accurate forecasts of the load flow on the power system. Lastly, ASTRE software, used to rapidly reproduce the long-term behaviour of power system voltages, was adapted to the utility's needs.

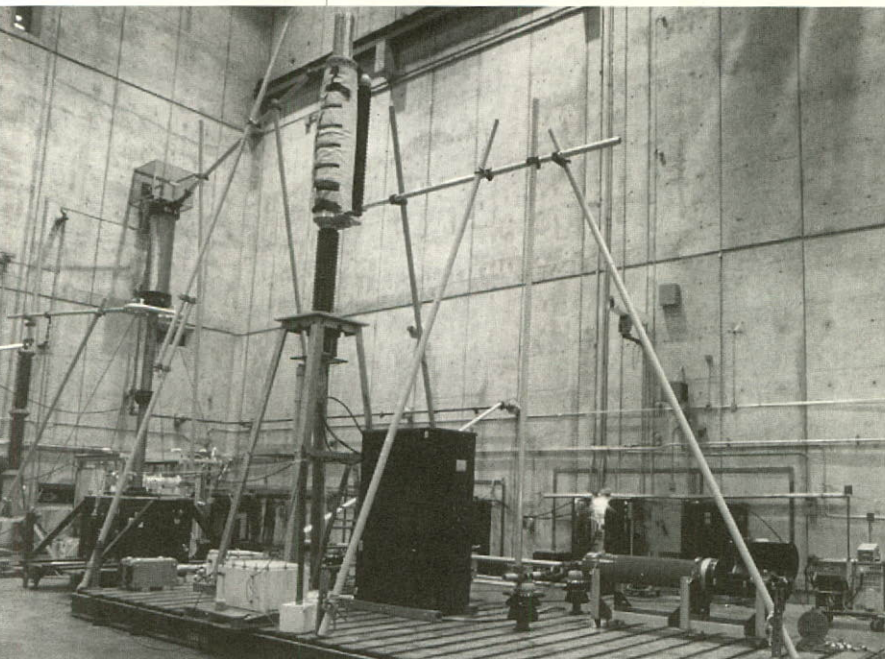
Electrical endurance of high-voltage SF₆ circuit breakers

Since current IEC and ANSI standards do not provide for electrical endurance tests for high-voltage SF₆ circuit breakers, it became necessary to devise a verification method to determine the weaknesses and assess the useful service life of this type of equipment. A multidisciplinary IREQ research team joined forces with GEC Alsthom T&D and Hydro-Québec's engineers to study the problem.

The method selected first involved compiling fault statistics for each 100 km of line in order to gather all of the faults that occurred on Hydro-Québec's power system over a 10-year period, from 1983 to 1992. A methodology was then drawn up to establish a test program based on an IEEE report produced by Électricité de France (EDF). In fact, the French utility is equally concerned about the need for a standard on the measurement of the electrical endurance of SF₆ circuit breakers.

Several parameters were considered in calculating the number of tests to be carried out. The main parameters included the type of faults (single-phase, ungrounded two-phase, two-phase-to-ground, three-phase), their rate of occurrence, and the distinction between transient and permanent faults. To minimize the cost of the tests, a simple test program was developed which covers all voltage ratings between 120 and 765 kV.

Electrical endurance tests on an SF₆ circuit breaker at the high-power laboratory.



Transmission

The test program was carried out in two stages, with the first corresponding to 12.5 years of service and the second to 7.5 years, for a total of 20 years of in-service electrical and mechanical wear. The results revealed that the GFX breaker for series-compensated lines – developed a few years ago by GEC Alsthom T&D and Hydro-Québec – successfully passed the electrical endurance test.

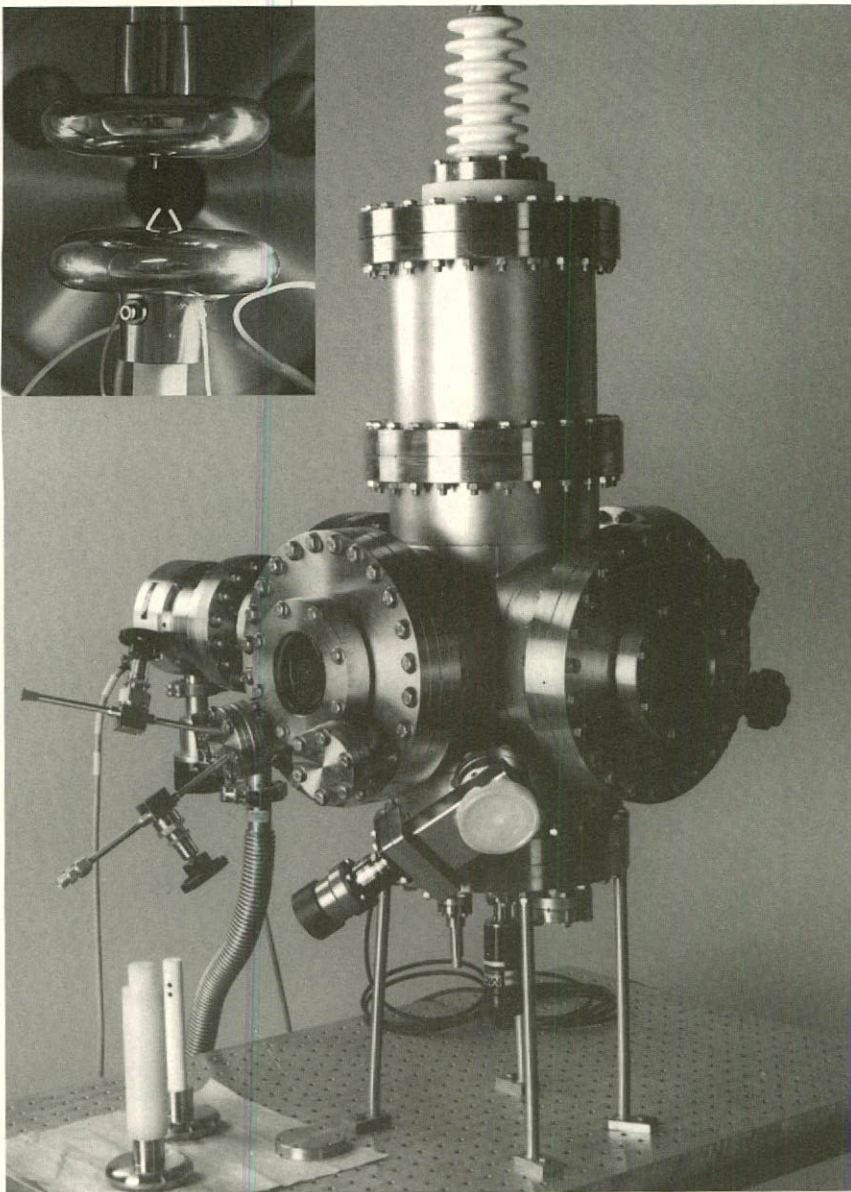
The project also served to validate high-performance sensors in view of their implementation in a monitoring program for the maintenance of high-voltage SF₆ circuit breakers. Lastly, a standards proposal is being drafted for submission to the IEC and CIGRÉ.

Study of the performance of SF₆/CF₄ gas mixtures used in HV circuit breakers

Circuit breakers that use mixtures of SF₆/CF₄ gases (sulphur hexafluoride/carbon tetrafluoride) were recently approved for use on Hydro-Québec's power system. However, not much data exists for characterizing the long-term dielectric behaviour of these mixtures considering their relatively recent use in circuit breakers, both in Québec and elsewhere in the world. IREQ was therefore asked by the utility's engineering and services division to evaluate the behaviour of the mixtures when used in HV circuit breakers. The study, conducted jointly with GEC Alsthom T&D, was completed in 1996.

The study involved analyzing the long-term physico-chemical behaviour of gas mixtures used in high-voltage circuit breakers. Researchers examined the effect of the by-products in the presence of an arc, a spark, and partial discharges which interact with the surfaces of solid materials, i.e. copper and ceramic Teflon. Four types of tests were carried out: three of them, performed on a reduced scale, involved arc-type discharges, with spark and partial discharges, while the fourth consisted in taking gas samples from a circuit breaker subjected to accelerated aging and then analyzing them. The approach that was used consisted of directly comparing observations of the gas mixtures with those of pure SF₆. Gas chromatographic analyses were conducted, along with a surface characterization of the solid materials.

Experimental installation and electrode assembly used to study the performance of insulating gas mixtures in HV circuit breakers.



The results of the study led researchers to believe that the overall physico-chemical behaviour and long-term behaviour of the SF_6/CF_4 mixtures (used in equal proportions) were comparable to that of pure SF_6 . Although there were a few differences, these were not sufficient to warrant classifying the gas mixture separately when used in HV circuit breakers.

Optical amplifier shelter

Hydro-Québec is in the process of installing a fibre optic communication system. Most of the fibres are incorporated in the overhead ground wire of high-voltage transmission lines. However, as these lines are thousands of kilometers long and the distance between substations is often considerable, intermediate sites had to be installed in order to be able to use regenerators to establish links between substations. Because of the size of the regenerators and their high energy use, sizeable infrastructures had to be installed at the intermediate sites.

To solve this problem, Hydro-Québec decided to use optical amplifier technology. Compact in size, simple and very reliable, amplifiers use little energy and make it possible to modify the transmission rate on the fibre or use wavelength multiplexing. However, in order to use this type of amplifier in the field at operating temperatures ranging from $+5^\circ\text{C}$ to $+25^\circ\text{C}$, a shelter had to be designed and a low power supply adapted to the requirements of the device.

At the request of the telecommunications division, IREQ researchers produced a compact installation in 1995 that is low cost, easy to maintain and uses little energy. The installation, which comprises a shelter capable of housing eight optical amplifiers and a secondary power supply, is equipped with an air conditioning system to keep the internal temperature at the specified level. The primary power supply is provided by the overhead ground wire of the line, while the battery-run secondary power supply ensures approximately eight days of autonomous operation. An intelligent charging system linked to IREQ monitors the entire power supply and controls it remotely.

A prototype was installed in November 1995 and has been undergoing tests under real climatic conditions. Measurements made over the past year have shown that the shelter adequately protects the amplifiers against temperature variations, water and condensation. The equipment used to control the internal temperature maintains the temperature at the specified level and uses little energy. Once the evaluation program has been completed, the system will be optimized with a view to implementing it on the transmission system.

Optical amplifier shelter being tested under natural conditions in 1996.



Installation of optical ground wires using the cradle-block method

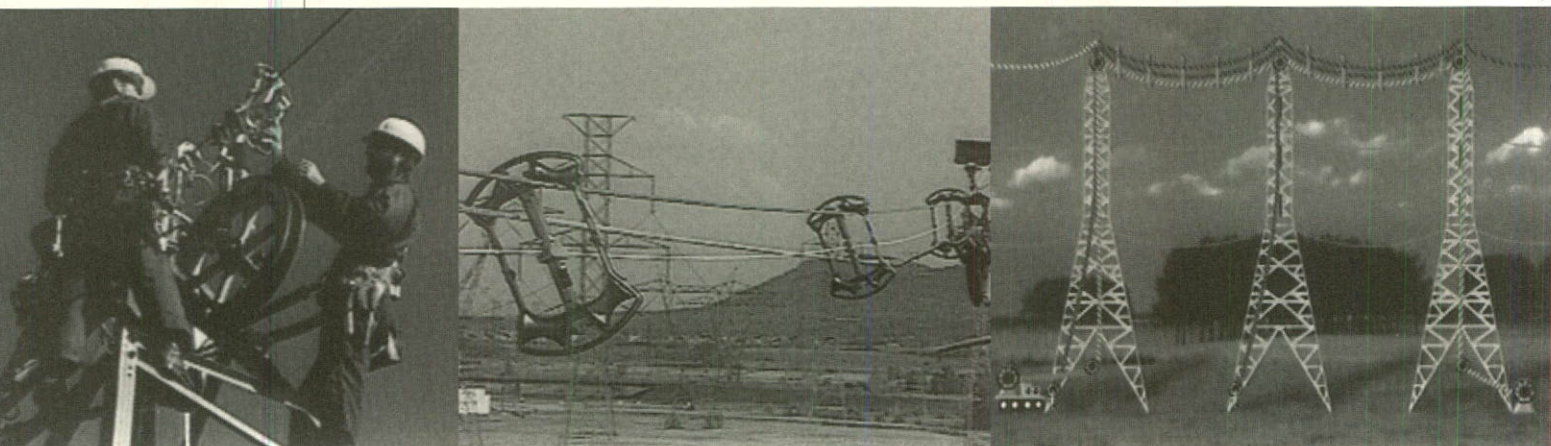
For nearly a decade, Hydro-Québec has been systematically replacing the overhead ground wires on its transmission system with overhead protective ground wires incorporating optical fibres (OPGW), which are not only used for telecommunications purposes but also act as lightning arresters. However, the installation of the optical ground wires had always presented certain problems on double-circuit transmission lines in service with a single wire attached at the top. Two circuits are laid out laterally in this type of line.

Simultaneous deenergizing of two circuits of the same line may only be done for a short period of time or may even be impossible to carry out due to operating constraints. Given these circumstances, it also proved difficult to plan and do the work within a reasonable period of time. In addition, the replacement of the overhead ground wire of certain double-circuit lines posed a serious threat to service continuity, equipment protection, and safety related to the stringing technique being used.

Hydro-Québec's telecommunications division therefore asked a group of utility engineers and IREQ researchers to find a way to install the optical ground wires while one or two circuits are in service. This meant that a certain distance had to be maintained to prevent accidental contact between the wires and the energized elements, ensure continuous grounding of the OPGW, and control the related stresses during installation. This work led to the development of an all-new method in 1996: the cradle-block method. Making use of a frame equipped with four bars laid out in the form of an "X" and an attachment system with a rope held in the centre, the method involves using the existing ground wire to support the OPGW during the installation.

In 1995 and 1996, many validation tests were carried out under laboratory conditions and on IREQ's experimental line with a view to ensuring worker safety, the integrity of the optical ground wire during the installation process, and equipment efficiency. In September 1996, a demonstration program confirmed that the cradle-block method was an ideal alternative to the former method. Simple, flexible and safe, the method is now ready to be implemented. One of its many advantages is the fact that its modular design precludes the use of costly protection structures, which are needed whenever a transmission line crosses a highway or other energized lines, and it may even be used to replace conductors.

Different views of the cradle-block method used to install optical ground wires on energized lines.



The icing rate meter: A device for measuring ice and its effects on power lines

A number of studies on the characteristics of ice and its effects on Hydro-Québec's 735-kV transmission system have led to the development of a new device, the icing rate meter. As research work progressed, it quickly became apparent that there was a need to monitor ice in real time so that interventions could be implemented in a timely manner after storms to minimize the resulting damage. The study results will thus allow the utility to design new system configurations in order to avoid the problem areas.

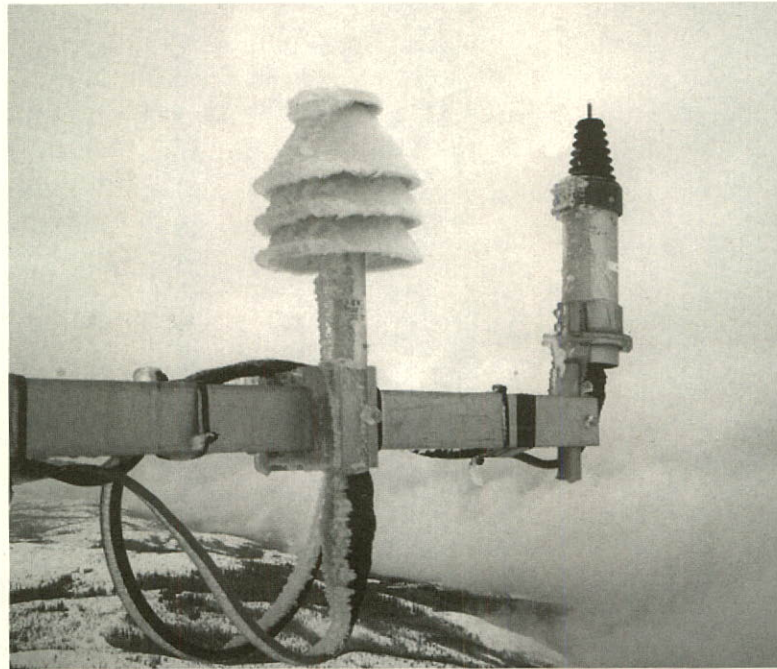
Use of a first-generation icing rate meter first showed the importance of increasing our understanding of how this device operates when subjected to different types of freezing rain conditions, as well as fine-tuning its control system to increase reliability. A second-generation icing rate meter which met these requirements was then developed, along with plans to market it.

The studies carried out in 1996 yielded highly promising results. One study, which combined the use of the icing rate meter with a real-time ice monitoring system ("SYGIVRE"), confirmed the device's high degree of sensitivity to various types of freezing rain conditions. To better define this sensitivity, tests were conducted at UQAC (Université du Québec à Chicoutimi) to evaluate the icing rate meter's response under various other conditions. These tests were supplemented by experiments carried out at four outdoor sites aimed at verifying the device's behaviour in actual conditions which are impossible to simulate in the laboratory. Lastly, it should be noted that for purposes of marketing the icing rate meter, Hydro-Québec contracted a Québec firm to manufacture a prototype to replace sensors that had been purchased at premium prices abroad.

The result of a collaborative effort between IREQ and UQAC researchers, the icing rate meter was developed at the request of the engineering and services division.

Although technical development of the icing rate meter has been completed, researchers will continue running tests in 1997 in a natural environment in order to gather the information required for the commercial version of the instrument. Subsequent to this last development phase, technical data sheets and specifications will be drawn up, a market study done and a manufacturer selected, after which the device will be marketed.

The icing rate meter measures ice in real time at the top of high-voltage towers.



Second version of data acquisition and control units

As a result of the increasing power and complexity of Hydro-Québec's power system, new requirements are constantly being added to substation and generating station control. Hence, the amount of data that have to be compiled and number of functions to be carried out had increased to such an extent that new control and monitoring equipment was required. Hydro-Québec has therefore developed a new computerized system – the ALCID-SICC – to deal with the increased complexity of operating system installation and management in substations and generating stations. "ALCID" (for "Automatismes locaux et conduite par intelligence distribuée" – Local automatic controls and distributed intelligent control) is used for the control and telecontrol of substations in real time, while "SICC" (which stands for "Système informatisé de conduite en centrale" – Computerized system for generating station control) does the same for generating stations.

Starting in 1990, one of the systems was installed in the 13 generating stations and 37 substations that were commissioned, including new facilities as well as rehabilitated or uprated ones. The ALCID-SICC, which comprises data acquisition and control units, integrates a large number of functions. To date, some 450 units valued at \$40,000 each have been installed on the power system.

Hydro-Québec then asked the firm GENTEC to develop a new version of the data acquisition and control units in keeping with the utility's present and future needs. Researchers developed an initial prototype, which easily passed all of the validation tests. The next phase – commercial production and manufacturing cost optimization – was then implemented with a view to developing a data acquisition and control unit tailored to the utility's needs at a cost reduction of 25%.

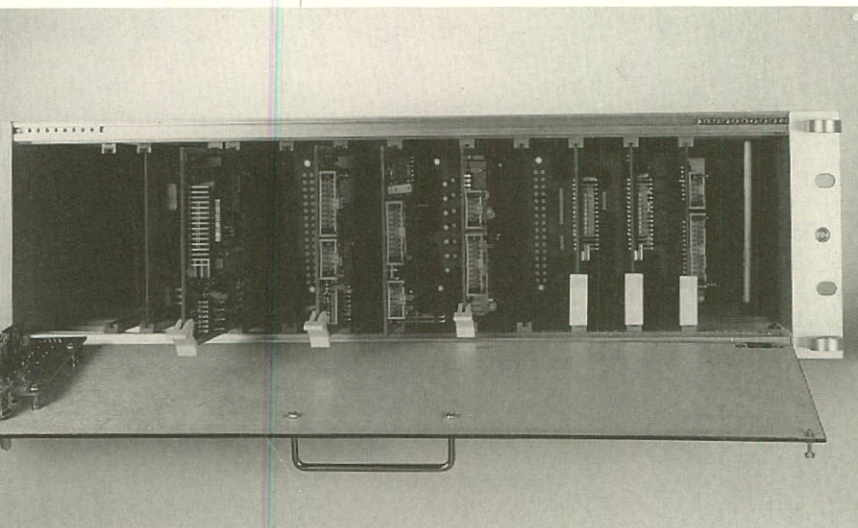
The work carried out in 1996 reduced unit production costs by 26%, which represents savings of \$10,000 per unit. Certification tests will be completed in March 1997.

The ICOS system: Synchronous control interface for circuit breakers

Designed to control the opening and closing of circuit breakers used for shunt reactor switching, the ICOS system ("Interface de Commande d'Ordre Synchrone" – Circuit breaker synchronous control) may soon be incorporated into the command chain of shunt capacitor circuit breakers.

Opening and closing of this type of circuit breaker causes frequent transient overvoltages which affect the quality of the electricity voltage delivered to commercial and industrial customers. To remedy this situation and improve the quality of the voltage supply, studies have been undertaken to improve the ICOS technology and adapt it to the opening and closing of shunt capacitor circuit breakers.

The ICOS system, designed to control the opening and closing of circuit breakers for shunt reactor switching.
(Photo courtesy of Snemo Ltd.)



Begun in 1994, these studies first allowed researchers to define characteristics regarding the duration of the opening and closing of GFX circuit breakers used to switch capacitors on the power system and to define the device's main operating parameters. Once the data were compiled, the utility asked the firm Snemo, which was in charge of manufacturing and marketing the ICOS system for shunt reactor circuit breakers, to develop a prototype. Completed in 1996, the ICOS prototype was incorporated into the command chain of a GFX circuit breaker and underwent validation testing at IREQ.

Work will continue in 1997 to ensure that this prototype meets Hydro-Québec's standards regarding control systems. Certification testing is also planned, and the ICOS system should be incorporated into capacitor reactor circuit breakers at Québec substation in 1998.

By switching the circuit breaker at the ideal time – i.e. the nearest millisecond – the ICOS system not only becomes a simple and cost-effective solution to the problem of transient overvoltages, but also serves to protect equipment against damage caused by circuit breaker operation, thus reducing equipment maintenance time.

The development work was carried out by electrical apparatus specialists on behalf of the power system studies department.

EMTP software restructuring

As electrical systems become increasingly complex and sophisticated, their operation and planning require ever more powerful high-tech tools. With this in mind, Hydro-Québec and Development Coordination Group (DCG) partners concluded an agreement aimed at restructuring the Electromagnetic Transients Program (EMTP).

EMTP is a simulation software program designed to reproduce the transient phenomena observed on the utility's transmission and distribution systems. A number of models of EMTP, the international standard in the field, have been designed to represent such phenomena within intervals ranging from a micro-second to a second.

Completed in 1996, the first phase of the project enabled researchers to draw up detailed specifications on the upgraded version of EMTP. Its new computing capacity could thus be used, within the current context of deregulation, to produce highly accurate forecasts of the available load flow, or to more accurately simulate the operation of equipment used to maintain the quality of the voltage supply.

The partners extended their initial agreement with a view to completing the final phase of the project, the primary aim of which is to develop new numerical software for simulating transient phenomena on the power system. In 1997, a prototype should be developed to demonstrate the software functions and capabilities.

The DCG coordinates all EMTP development activities and heads research projects on the methods used to simulate transient phenomena. At Hydro-Québec's end, work related to the project is carried out on behalf of the power systems and transmission planning department and is headed by IREQ's power system software and algorithms division.

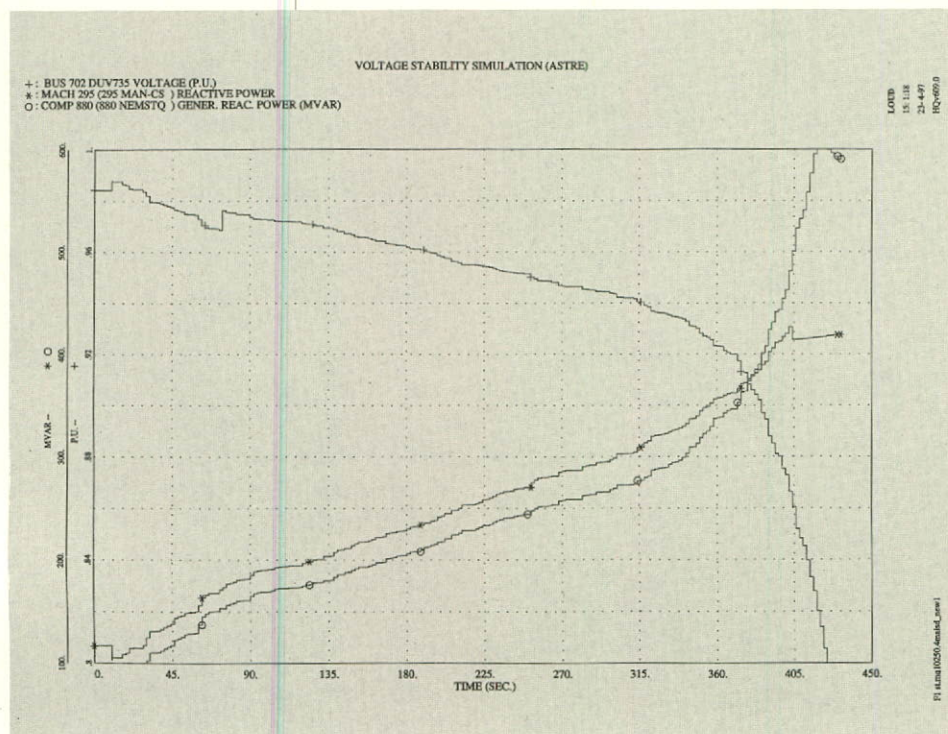
As a final note, it should be mentioned that the DCG has many R&D partners, including Hydro-Québec and several other firms, as well as organizations from the international electrical industry based in Canada, the United States, Japan, Brazil and Europe.

ASTRE: Software for analyzing the stability of power system voltages

Simulation studies are crucial for analyzing voltage stability and transmission system security. Until now, the program used for this purpose required up to four hours to provide highly detailed simulation of power system behaviour in the five minutes following a disturbance. Considering the number of incidents that must be studied in order to obtain a significant analysis, it obviously took too long to perform this operation and, in most cases, the amount of detail was unwarranted.

Recognizing the need to optimize the transmission system capacity, Hydro-Québec's power system planning department asked IREQ to adapt ASTRE (for "Analyse de la Stabilité de la Tension des Réseaux Électriques" – Software for analyzing the stability of power system voltages) to its needs. An agreement regarding a partnership and technology transfer was therefore drawn up with the software's developer, the Université de Liège in Belgium. The technology transfer allowed IREQ to develop the software in order to tailor it to the utility's needs. All that remained was to develop an assessment program for demonstrating ASTRE's ability to reproduce the long-term behaviour of power system voltages, as well as the program's user-friendliness, efficiency and ease of integration into the user analysis environment provided by IREQ.

Sample analysis curves generated by the ASTRE software program.



In 1995, a high-performance version of ASTRE was tested by the utility. This version decreased the time required for simulating power system behaviour from several hours to a few minutes, while maintaining a sufficient level of accuracy in most cases. In 1996, ASTRE was installed in all of the workstations of the engineers in charge of assessing transmission limits and related strategies.

Discussions are currently under way regarding the marketing of this highly promising technology with a view to adding ASTRE to IREQ's power system analysis software that is already commercially available.

Lastly, it should be noted that the ASTRE software program has the potential to be used for real-time analysis of power system security. This work is being planned for 1997 and will be covered in a partnership agreement with the Université de Liège.

Distribution

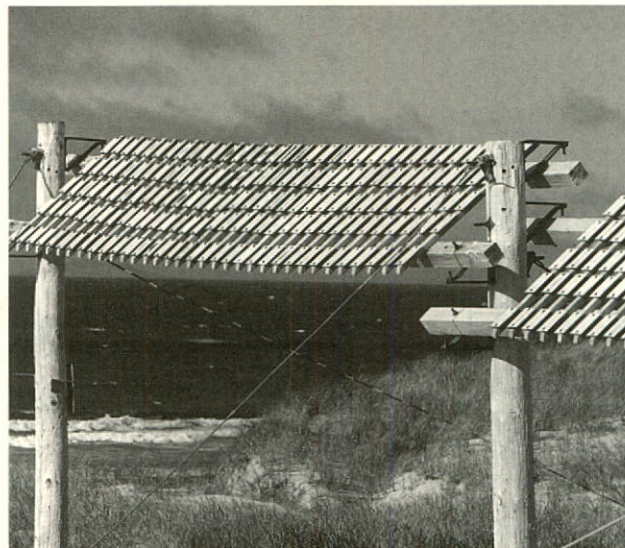
In the area of distribution research, there were two key achievements in 1996. A study focused on coating materials used to counter the deterioration of distribution system equipment operated in areas characterized by high levels of humidity and salt air. Powder coatings, water-based paints and high-solids paints were studied in two harsh environments: a salt fog chamber and the coastal region of the Magdalen Islands.

A new device was developed for the in situ detection of defective insulators on suspension insulator strings through measurement of their electrical impedance. A telescopic pole is used to operate the device and the electrical insulation is maintained through two modules. Studies have confirmed that use of such a device would substantially lower distribution system maintenance costs.

Other studies carried out in 1996 involved wood poles, power quality, robotized maintenance tasks in the underground distribution system, fuse cutouts, current-limiting circuit breakers, superconducting magnetic energy storage, and current limiters.

Evaluation of protective coatings used for outdoor electrical distribution equipment

Some distribution system equipment is operated in environments that cause it to deteriorate more quickly, such as those characterized by a high level of humidity and salt air. To remedy this situation, a project was initiated to study various protective coatings such as powder coatings, water-based paints, and high-solids paints with a proportion of volatile organic content (VOC) less than 420 gL^{-1} . The study was carried out in two harsh environments: a salt fog chamber and the coastal region of the Magdalen Islands.



The ability of the coatings to preserve the integrity of hot-rolled mild steel and 304 L stainless steel was first characterized using advanced electrochemical and visual inspection techniques. Their vulnerability to UV rays was then assessed, after which mechanical tests were carried out in view of completing a thorough characterization of the coatings. The aim was to find ways of countering equipment disintegration, identify new-generation coating materials which complied with environmental standards, preserve the appearance of in-service installations, and improve the efficiency of paint repair work on equipment showing signs of corrosion.

Installation in a natural environment used to study coatings that protect equipment against corrosion.

Distribution

To meet these objectives, the coatings had to fulfill the following criteria: be low in cost and suitable for paint applicators used for standard equipment; be environmentally friendly; be capable of combatting the degradation of equipment as well as the formation of blisters and resulting loss of adherence, while at the same time resisting the effects of UV rays. Lastly, the coatings had to be resistant to abrasion, direct impact, and elongation at break. Thus, a high-performance coating would preserve equipment integrity for about two decades, even in a highly hostile environment.

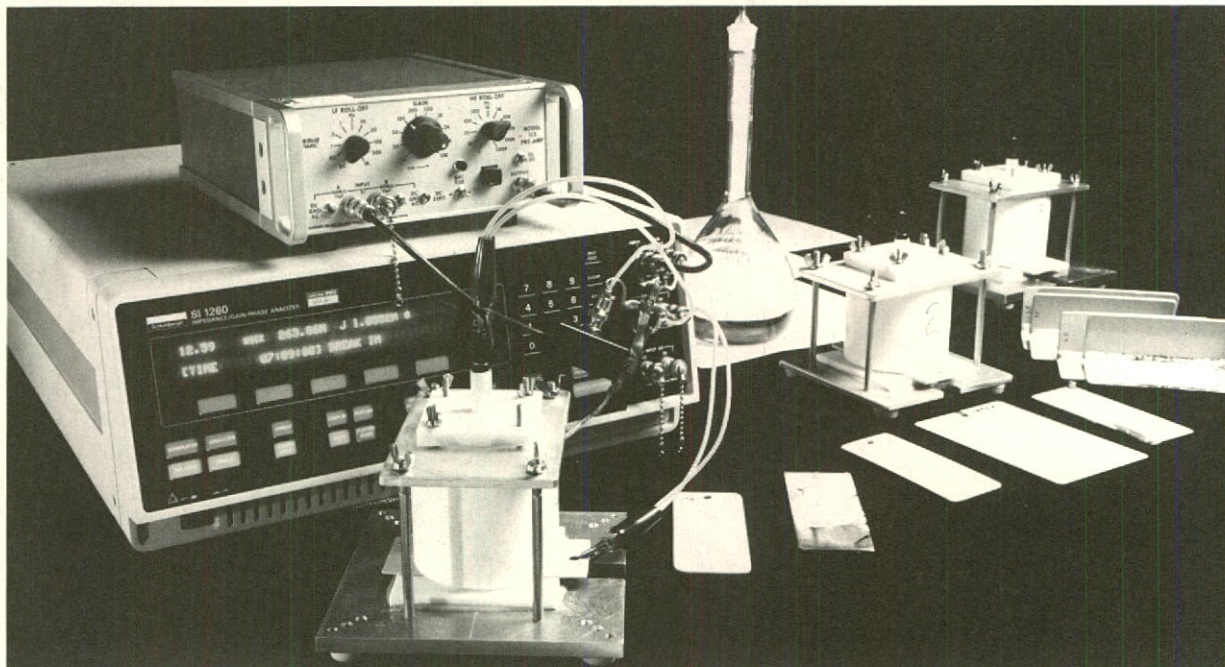
Carried out at the request of the distribution division, the study was funded in part by the Canadian Electrical Association, which had reached an agreement with IREQ to identify coatings that fulfilled environmental requirements regarding VOC reduction, as more and more countries are adopting regulations to this effect. It should be noted that the firms SIXPRO (Québec) and Powertech Labs (British Columbia) were responsible for applying the paints. As all the tests were successfully completed, the drafting of the final report was begun towards the end of 1996. The results of the study, to be published in a major scientific journal, will also be included in a series of recommendations and will be presented at the Electrochemical Society's Spring Symposium on Corrosion in Montréal.

Development of a suspension insulator monitoring system

A new monitoring device, specially designed for porcelain insulators on the distribution system, has been developed for the purpose of detecting defective insulators on suspension insulator strings. Studies have confirmed that its use would substantially decrease distribution system maintenance costs.

At the request of the utility's maintenance division, the project team undertook the development of the suspension insulator monitoring system, known as the "VIS 200." One of the system requirements was in situ and highly accurate monitoring of insulator performance. The system also had to be light, since it would be operated by only one person from the ground using a telescopic pole. The challenge was sizeable, but the project team proved up to the task and the suspension insulator monitoring system is now ready to be installed on the distribution system.

Laboratory installation used for the electrochemical characterization of corrosion-resistant coatings.



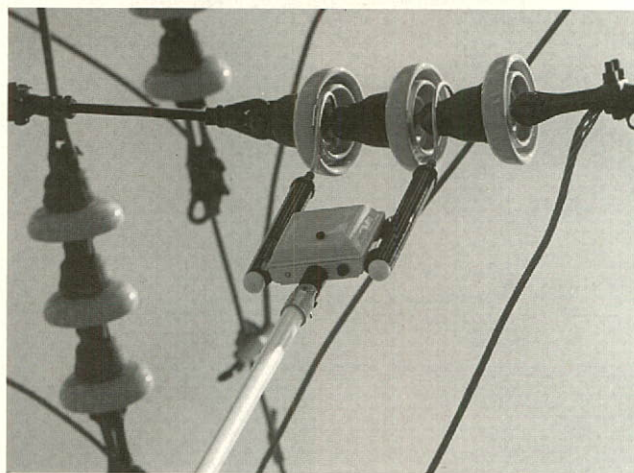
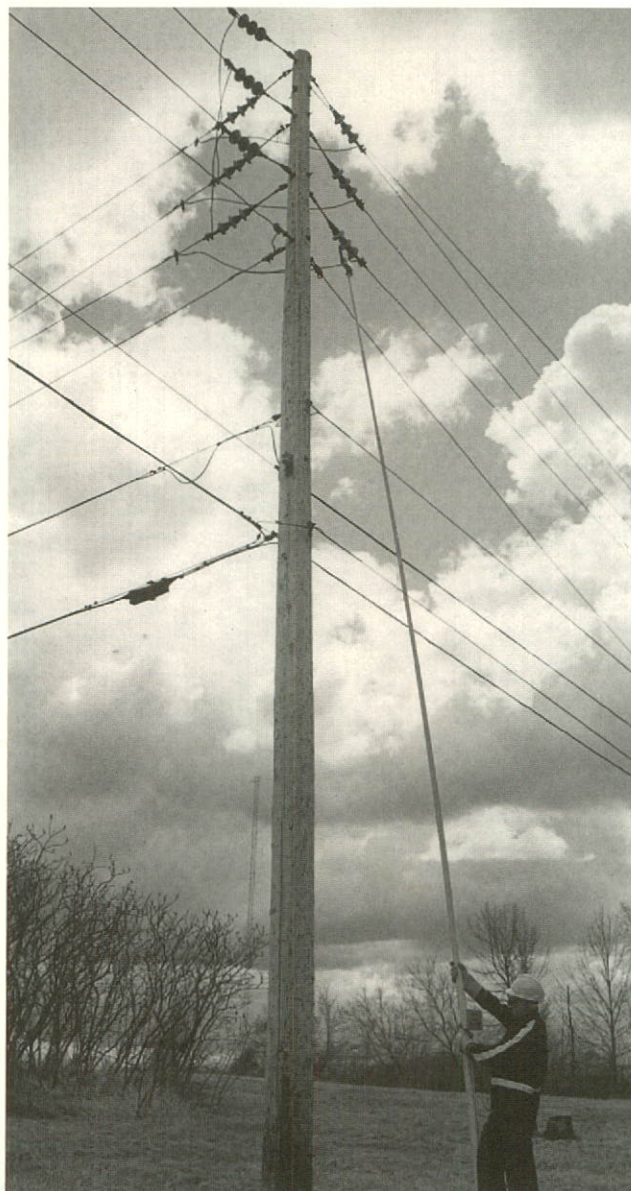
Distribution

Demonstration of a prototype used to inspect distribution system insulators.

The VIS 200 detects defective insulators by measuring their electrical impedance. It comprises a monitoring module, equipped with electronic circuits and microprocessors which are moved along the insulator string using the pole, as well as a data acquisition, control and processing module. Communication between the two modules is done by UHF radio to ensure that the electrical insulation is maintained.

Development of the device progressed rapidly. The base technology for the system was chosen in 1994, after which feasibility studies were carried out and two prototypes were built. In 1995, the prototypes were tested in the laboratory and in the field. Once the necessary improvements were made, ten pre-prototype VIS 200 units were built. They were completed in 1996 and are expected to be delivered in 1997. A licensing agreement will be signed with a private firm for the large-scale production and marketing of the VIS 200.

Because of its high precision and its ability to perform in situ monitoring of in-service insulators, the VIS 200 has a significant edge over current techniques.

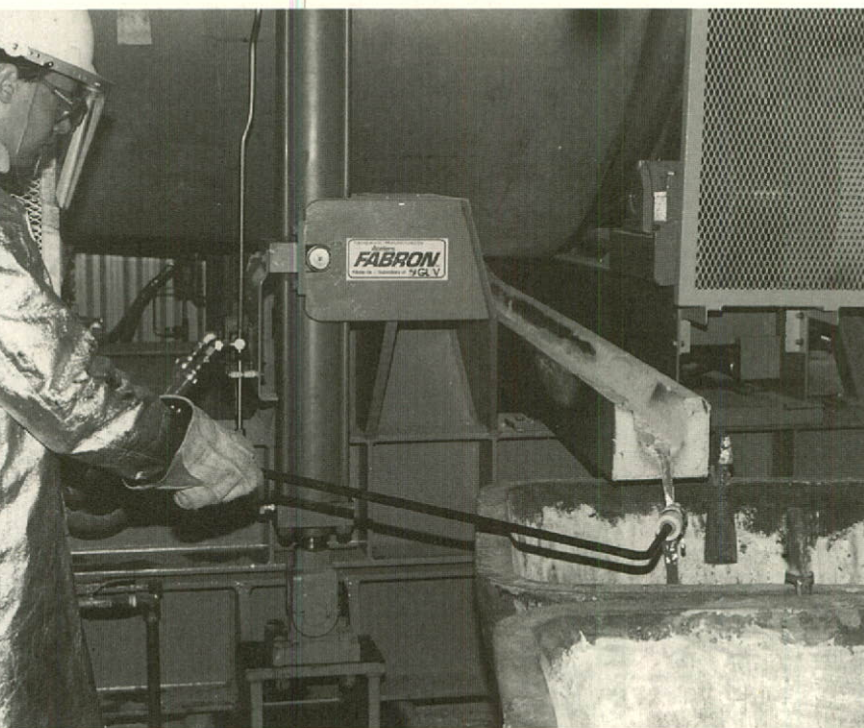


Utilization

Hydro-Québec has been involved in several R&D projects regarding the utilization of electricity in the residential, commercial, institutional and industrial sectors. For instance, a series of tests were conducted on the DROSCAR technology, used for the processing of dross, at Hydro-Québec's LTEE pilot plant, and confirmed the considerable potential of this technology. Moreover, a number of development and demonstration activities were carried out on another technology, the induction-heated screw, which is part of a licensing agreement. Eight firms commissioned studies on the drying of aluminum-processing and de-inking sludges, the drying of lime, and the heating of silicon granules.

The past year saw a number of developments on several fronts: thermal heaters were installed in several homes in order to evaluate their heating efficiency and effect on the customers' comfort and energy consumption; a test bench was used to assess the susceptibility of 150-hp variable-speed drives (VSDs) used in industrial processes; a technical guide on VSDs was produced along with training sessions on electromagnetic compatibility; a study was carried out on the economic impact of harmonic disturbances; and a test bench was built at LTEE in view of developing and assessing new energy-efficient HVAC systems and equipment.

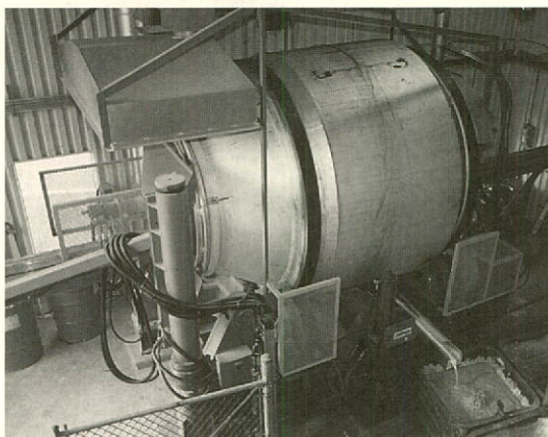
Laboratory testing on the DROSCAR technology used to recover aluminum from dross.



DROSCAR process

The DROSCAR process is based on a technology that allows aluminum to be recovered from dross. It is an alternative to existing processes which bypasses their inherent problems. Developed by LTEE (Hydro-Québec's electrochemical and electrical technology laboratory), the new process recovers aluminum without using salt, water or gas, or oxidizing the metal.

The DROSCAR technology consists of a rotary furnace revolving around two horizontal graphite electrodes. An electric arc is held between the electrodes to heat the charge. The rotary furnace is operated horizontally to prevent the graphite and electric arc electrodes from entering into contact with the charge. In addition, the furnace revolves a full 360° to agitate the charge and more evenly distribute the energy from the electric arc. Finally, the furnace has the advantage of being airtight, thus preventing any air from seeping in, destabilizing the electric arc and oxidizing the molten metal.



Utilization

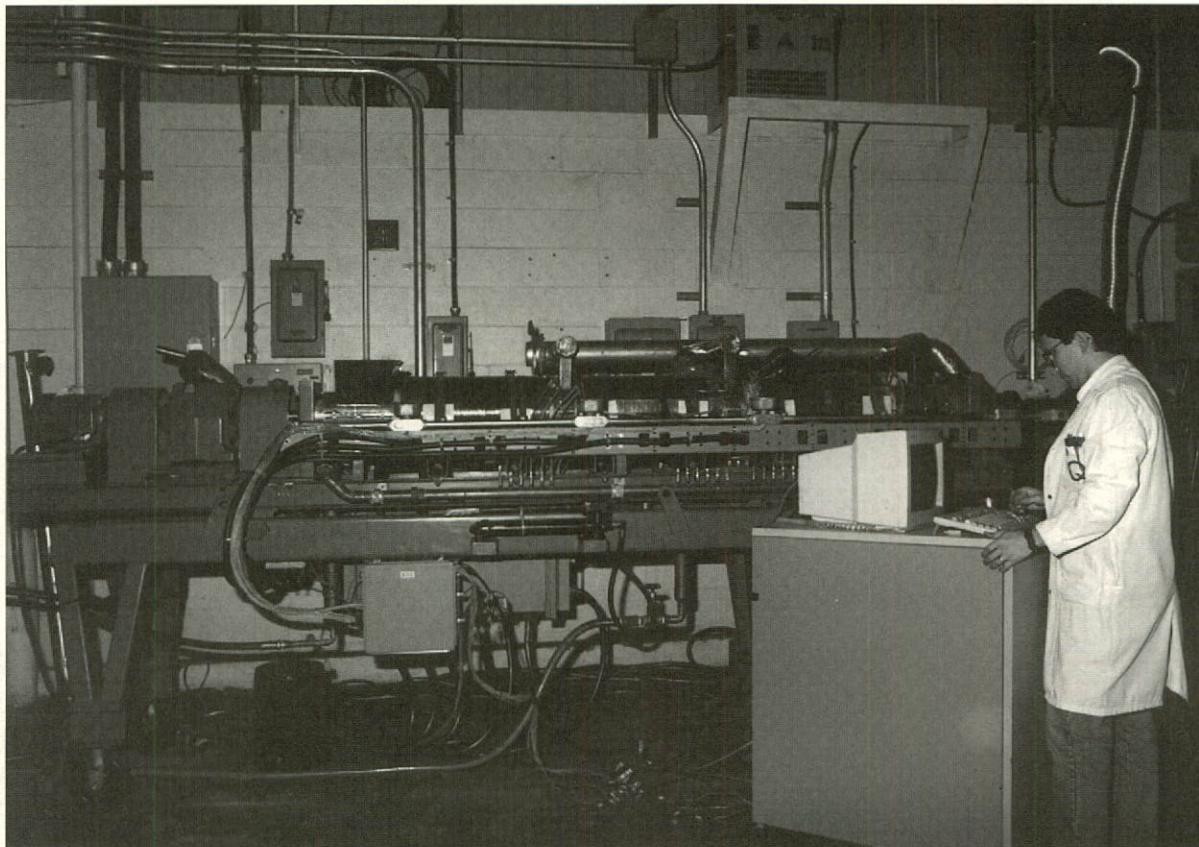
The technology's considerable potential was confirmed in 1996 when a series of tests were carried out at LTEE's pilot plant. The firm Société des technologies de l'aluminium du Saguenay (STAS) also calculated its implementation cost based on the design specifications drawn up by LTEE. Lastly, it should be pointed out that the DROSCAR process may be commercialized in the near future since negotiations are currently under way with a French firm regarding implementation of the technology in a plant with an annual capacity of 7000 metric tonnes.

The DROSCAR process was developed by LTEE at the request of the utility's mines and metallurgy division.

New applications for the induction-heated screw

In 1989, Hydro-Québec's electrochemical and electrical technology laboratory, LTEE, undertook to develop an induction-heated screw for the treatment of granular and non-cohesive material, as well as various types of sludge. The device consists of a screw inserted into a casing heated by electromagnetic induction at the frequency of the power system using copper coils. This compact system uses electrical energy very efficiently and handles heating, drying, fusion and curing operations.

Testing at LTEE of the induction-heated screw used for the treatment of granular and non-cohesive material.



Utilization

The electrotechnologies department has designed a prototype of a 150-kW screw with a 15-cm diameter, used to fine-tune the technology and conduct studies requested by industrial customers. Between 1992 and 1996, applicability tests, for the most part carried out under phase III of Hydro-Québec's Electrotechnology Implementation Assistance Program, were performed at the request of 18 Québec firms. In 1996 alone, eight firms commissioned studies on the drying of aluminum-processing and de-inking sludges, the drying of lime, the fusion of a mixture of paraffin and sawdust, and the heating of silicon granules.

A licensing agreement was also reached with Bectrol, a Saint-Laurent firm, regarding the marketing of the technology. The agreement included a joint development facet aimed at supporting the design of induction-heated systems, reducing their cost to increase their market potential, and developing new industrial applications.

In view of the promising results of several feasibility studies, a manufacturer should be involved in the near future, leading to an initial industrial implementation in 1997.

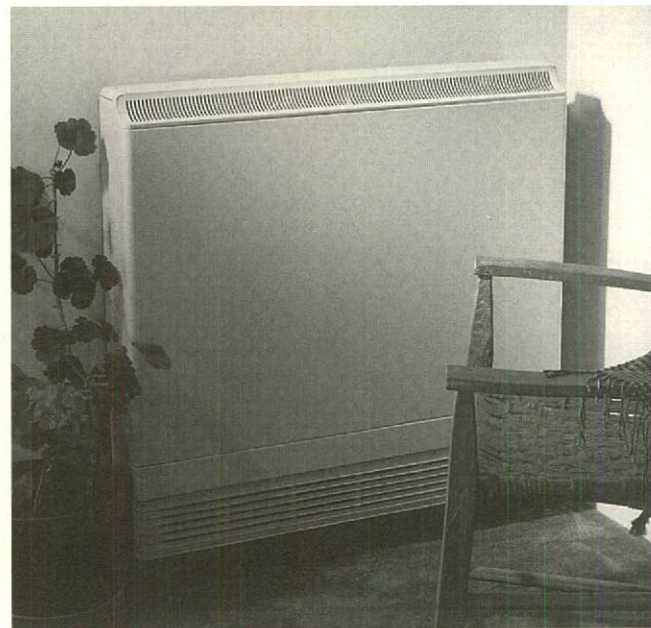
Storage heaters and energy management

Given the competitive context of the electrical industry, Hydro-Québec has been seeking ways of meeting the needs of residential customers eager to manage their own energy consumption. A project was thus initiated to evaluate, under real conditions, whether it is technically feasible to use local storage heaters (centralized heating) or central storage heaters (decentralized heating) for energy management purposes.

These two types of heating devices would in fact allow customers to reduce their electricity bill if they were able to transfer the heating load from peak to off-peak periods, and if the utility's new rate DH (time-of-use rate) was applied. Use of the new rate would also minimize the impact of potential rate D increases since Hydro-Québec's savings during peak consumption periods could then be passed on to its customers.

As part of this project, local and central thermal heaters were installed in several homes which had been equipped with measuring devices used to evaluate the heaters' energy efficiency and their effect on the customers' comfort and energy consumption. The experiment showed that even during intense cold spells, the central storage heaters were able to offset any power demand using only the heat that had been stored overnight, without adversely affecting the residents' comfort.

Local storage heaters being tested in a customer's home.



Utilization

Moreover, the local storage heaters fulfilled the purpose of shifting the consumption period while increasing customers' level of comfort as compared to baseboard heaters. This was confirmed by most of the 88 customers who took part in the study, with 86% expressing satisfaction.

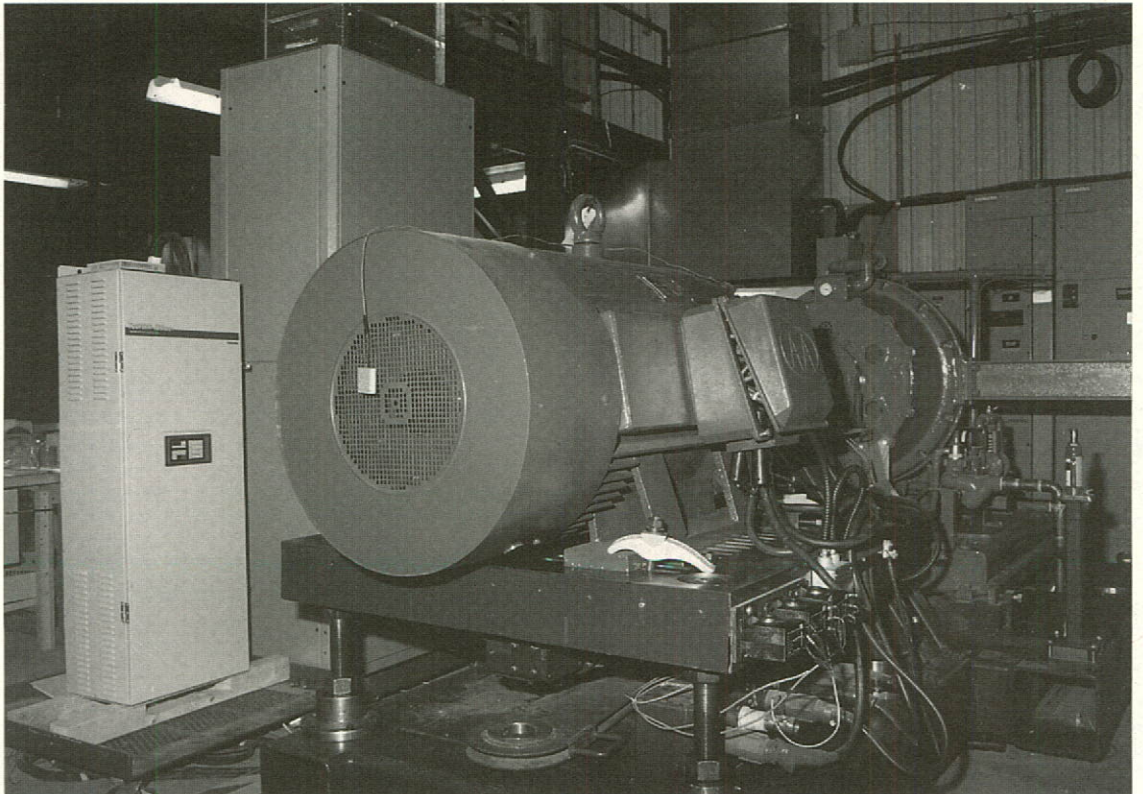
Carried out at the request of the design and residential markets department, the project is expected to continue in 1997 with the development of rate DH marketing tools that use thermal storage heaters.

Commissioning and accreditation of VSD test bench

A major facility used to test the electromagnetic compatibility of electric and electronic equipment as well as to carry out related research activities was commissioned at LTEE (Hydro-Québec's electrochemical and electrical technology laboratory) at the end of 1995. This unique facility consists of a test bench, used since 1992 for measuring the efficiency of electric motors, while its key component is a 432-kVA three-phase amplifier which, at high power levels, generates voltage waveforms corresponding to a variety of disturbances on the power system.

In accordance with LTEE's mission, the work carried out on the test bench is related to the utilization of electricity and more specifically deals with the study and evaluation of the susceptibility of equipment used in industrial processes. It should be noted that another purpose of the test bench is to provide a range of commercial services to users and manufacturers of electrical equipment.

Test bench used to test electromagnetic compatibility of electric and electronic equipment.



Thus, in 1996 the available power level was increased and a surge generator was installed to simulate the effects of lightning. In addition, an application was submitted to the Standards Council of Canada to extend the scope of accreditation of ISO-Guide 25, which LTEE obtained in 1993 for the measurement of motor efficiency.

In 1996, LTEE undertook a project with a view to studying and characterizing the susceptibility of 150-hp variable-speed drives (VSDs). It is well known in the industry that VSDs cause major production losses. The project, carried out jointly with the Power Electronics Applications Center (PEAC), a laboratory of the Electric Power Research Institute (EPRI), also served to establish test procedures and draw up specific standards. Funding for the work carried out at LTEE was provided by the utility's business customers and metering division.

The VSD characterization project is expected to be completed in 1997. Commercial testing services will continue to be offered and major efforts will be geared toward developing this market.

Training sessions and technical guide on electromagnetic compatibility

Hydro-Québec has set up a program to produce a series of technical guides on electromagnetic compatibility for its personnel and customers. Training sessions to this effect are also being planned. As part of the project, LTEE was asked to draw up a guide on variable-speed drives (VSDs) and prepare a course on electromagnetic compatibility.

Subsequent to the work carried out in 1995, a first guide on the electromagnetic compatibility of VSDs was produced in 1996. About 140 pages long, the manual is the product of an in-depth review of literature on the subject. It also includes case studies as well as a number of appendices which present some technical concepts in greater detail. The guide was distributed in November 1996 to some 150

Hydro-Québec staff members at an LTEE seminar. The workshop was primarily intended for electrotechnical engineers, representatives from the major client accounts division, commercial representatives and technicians, personnel assigned to energy efficiency programs, and engineers involved in power system planning.

Another project, aimed at preparing a week-long intensive, university-level course on electromagnetic compatibility, was initiated in 1996. To this end, a working group was set up to draft the textbook for the course. The group consists of engineers from a consulting firm with considerable practical expertise in the field, as well as university professors specialized in power electronics.

The course, to be held in 1997, is scheduled to be given first to Hydro-Québec personnel and then to the utility's customers. The textbook will serve as the basis for a technical manual. Regarding the variable-speed drive guide, in 1997 it will be distributed primarily to engineers in the electrotechnical industry.

Funding for this project was provided by the business customers and metering division.

Study of the economic impact of harmonic disturbances

The equipment used by Hydro-Québec's industrial, commercial and residential customers is creating increasing numbers of harmonic currents on Hydro-Québec's distribution system. These currents in turn create thermal overloads which cause electrical equipment to age prematurely, thus reducing their useful life both on the utility's power system and at the customer's installations. Harmonic currents may also cause misreadings of a customer's electricity consumption by slowing down the meter.

The utility therefore initiated a major study in 1994 on the economic impact of harmonic currents, which, in fact, had never before been assessed either for the utility or its various customers. The results of this study will help the utility make informed decisions as to whether or not it should implement control mechanisms – i.e., often costly measuring devices and software – as well as draw up a plan for implementing such mechanisms.

Carried out by IREQ's electrical apparatus department, the study had two objectives: the first was to determine the short-term impact of incorrect readings and energy losses caused by harmonic currents; the second was to assess the long-term impact of a decrease in the service life of electrical apparatus. Completed in 1996, the study showed that harmonic currents caused average annual losses of \$4 per customer, an amount which could rise fivefold if the rate of harmonics continues to increase.

It should be noted that this study is in line with Hydro-Québec's strategic plan, in which the utility has stated that it intends to offer, by the year 2000, a base product that complies with international standards as well as optional products tailored to its customers' specific needs. A similar study is currently being conducted on voltage unbalance. Initiated in 1996, the study should be completed during the coming year.

Test bench for HVAC technologies

The highly competitive market for the many different sources of energy used for the heating, ventilation and air conditioning (HVAC) of buildings and, especially, the replacement of former refrigerants that were environmentally harmful have stimulated research and development activities in this field. New and more efficient HVAC technologies that use less energy and are more environmentally friendly have thus been developed, including systems based on the concept of electrical heat pumps, which are very promising from an energy efficiency perspective.

In an effort to favour the implementation of new energy efficient HVAC systems in the commercial sector, the utility's marketing division asked LTEE to build a test bench for evaluating this type of equipment, in addition to contributing to its financing. The test bench comprises two heat sources, one cold (-30°C to 10°C) and the other hot (-20°C to 90°C), linked to two closed circuits and interconnected by an intermediate heat exchanger. The transfer of energy between these two circuits allows the thermal levels required during testing to be controlled. In addition, the test bench has a considerable degree of flexibility as a result of the circuits: for instance, several operating modes of a wide variety of HVAC systems may be simulated on a reduced scale.

The test bench offers a wide range of possibilities. For instance, it may be used to validate system performance, assess the energy efficiency of different heat exchangers, and characterize the energy performance of new heat pumps which use various artificial or natural refrigerants. The test bench also serves to measure the performance and efficiency of ice production and transport for air conditioning as well as verify various cool-storage technologies. Various theoretical simulation models may also be validated at lesser cost. The installation also facilitates the study of the transfer of heat and transfer properties of new refrigerants as well as the testing of rooftop units and other heating and air-conditioning equipment. Lastly, the new test bench may be used for the development of new products.

Diversification

Hydro-Québec, in partnership with 3M, continued work on Phase II of a joint project carried out for USABC regarding the development of batteries for electric vehicles and other applications. Phase II is intended to demonstrate the ACEP module technology in 1996 and the battery technology in 1997.

The Euro-Québec/Hydro-Hydrogen project, for its part, passed major milestones in the past year. Development and demonstration activities were successfully carried out in Québec, while two city buses running on hythane were integrated into Montréal's transit system as part of a nine-month program, thus demonstrating the advantages of this fuel. Aeronautics research proved the feasibility of an airplane engine running on hythane. A high-tech container was developed for the transportation and storage of liquid hydrogen and a new firm, HT2, was created.

The utility also developed and assessed, in collaboration with industrial partners, a membrane separation process and prototypes for the treatment of waste acids laden with heavy metals. Other research work led to the development and evaluation of a membrane separation technology used to purify the electrolytes required for the production of sodium chlorate, a chemical used to bleach paper pulp.

Polymer-electrolyte battery (ACEP) development project

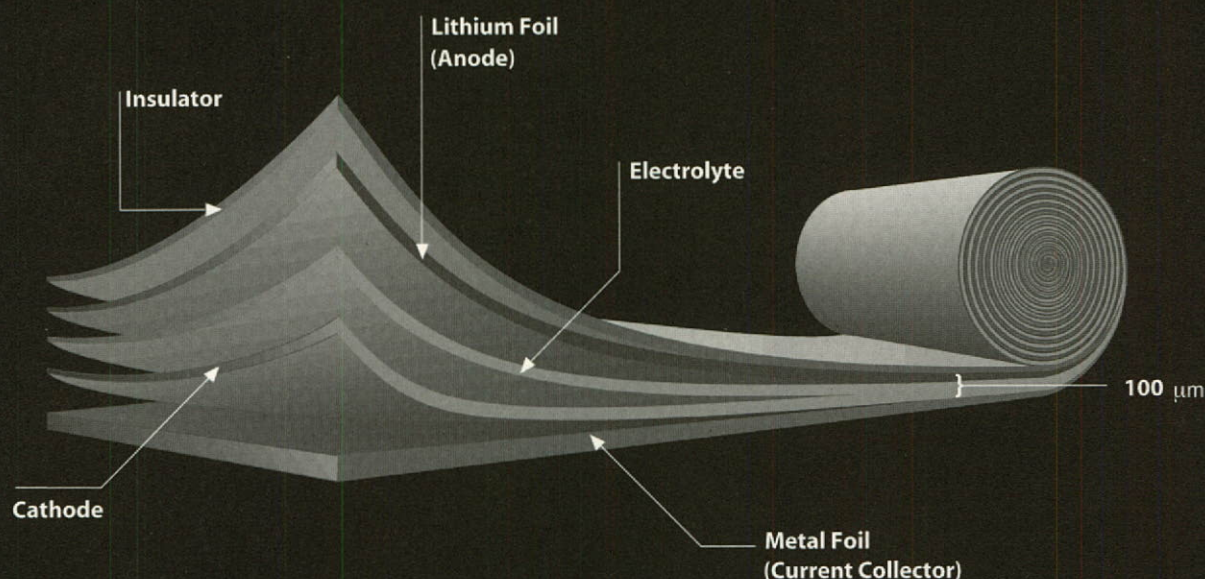
The ACEP project involves the development of polymer-electrolyte batteries for three areas of application: electric vehicles (cars and small off-highway motor vehicles), activities requiring storage batteries (such as telecommunications), and electronics.

Since 1980, Hydro-Québec has filed more than 60 patents to protect the base technology of all-solid lithium-polymer batteries, the most promising project for the next generation of high energy density batteries. This intellectual property and technology have attracted the interest of first-rate international partners.

Hydro-Québec thus joined forces with the Japanese manufacturer Yuasa in 1990 with a view to developing small primary rechargeable batteries. In 1993, it signed an agreement with the United States Advanced Battery Consortium (USABC) for the development of large batteries. The USABC, it should be noted, is made up of the three major car manufacturers (Ford, Chrysler and GM) and the Electric Power Research Institute (EPRI). This partnership was a fruitful one, as demonstrated by the three development milestones that were passed in 1996.

In December 1995, Hydro-Québec and 3M successfully completed Phase I of a project valued at US\$33 million, after which they undertook the second phase of the agreement, which has an additional budget of US\$27.4 million spread out over two years. Phase II is intended to demonstrate the ACEP module technology in 1996 and the battery technology in 1997.

An important point to mention is that half of the R&D expenditure for these two phases involves activities carried out in Québec, i.e. at IREQ and LTEE for the actual research, and at ARGO-Tech, a wholly owned subsidiary of Nouveler, for the assembly of the prototypes. In addition, in 1996, Hydro-Québec doubled the total volume of prototypes assembled at ARGO-Tech compared with 1995, and in late 1996, the first two 20-V modules were assembled and started up.



Assembly of an ACEP electrochemical fuel cell in cylinder form.

LTEE, for its part, commissioned a pilot facility for laminating metallic lithium for the production of ultrathin film, which will be needed for the work planned for 1997. Hydro-Québec completed, in collaboration with CANMET, an extensive program aimed at demonstrating the inherent safety of all-solid lithium-polymer battery technology.

Lastly, IREQ drew up and submitted to USABC an outline of the R&D work that still has to be completed in order to meet the cost and performance objectives established by the consortium with a view to marketing the first electric-vehicle batteries by the year 2000. The R&D program is currently being discussed prior to the signing of a two-year contract under Phase IIb of the project.

In 1996, the Japanese manufacturer Yuasa completed construction of a plant for manufacturing small LPB-type non-rechargeable primary batteries for signal-emitting identification cards. Through its subsidiary, Nouveler, Hydro-Québec financed 25% of Yuasa Acep's share capital. The utility made an initial investment of \$1.5 million in 1996. Yuasa delivered the first commercial units in September 1996.

Assembly and demonstration of 20-V modules and the batteries containing the modules are slated for 1997. Phase IIb of the agreement should be concluded with USABC this year (see above). Lastly, Hydro-Québec hopes to approve the investment plan for a pilot plant to manufacture small batteries for electric vehicles, other applications, and the various project activities.

Euro-Québec/Hydro-Hydrogen project

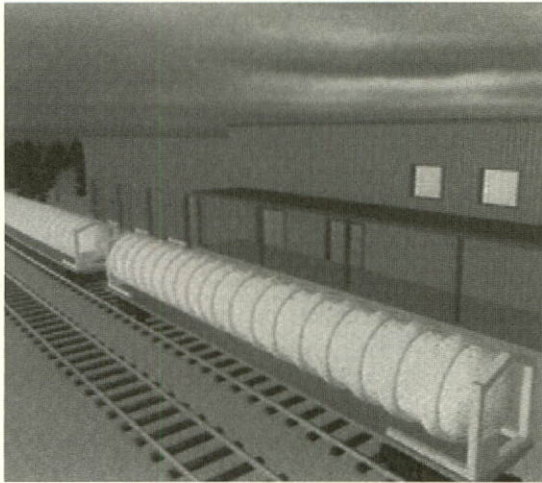
Now that environmental protection has become a worldwide concern, hydrogen – an environmentally friendly energy source whose combustion produces nothing more harmful than water vapour – is already playing a major role as an alternative fuel. Accordingly, Hydro-Québec, the Québec government and Québec industries have initiated the Euro-Québec/Hydro-Hydrogen project jointly with European firms and the Commission of the European Communities. The aim of the project is to develop means of transportation (cars, planes and buses) that run on hydrogen or hythane – a mixture of 20% hydrogen and 80% natural gas – and design appropriate infrastructures, i.e. containers for transporting the hydrogen and specialized tanks.

In 1996, the project team passed significant milestones with the successful completion of the development and demonstration phase in Québec. Under a nine-month program, two city buses running on hythane were integrated into Montréal's transit system. This experiment not only confirmed the advantages of hythane as a fuel but also showed that it costs less to use than diesel fuel. Furthermore, the amount of nitrogen oxide (NO_x) emitted by the two hythane-fueled buses was 44% lower than that of buses running on natural gas and 66% lower than that of buses running on diesel fuel. Moreover, aeronautics research proved the feasibility of an airplane engine running on hythane, with NO_x emissions 20 times lower than those reported in the scientific literature.

In 1996, two city buses running on hythane were integrated into Montréal's transit system over several months.



High-tech container used to transport liquid hydrogen.



As for infrastructures, a high-tech container was developed for the transportation and storage of liquid hydrogen. In 1997, two prototypes of the container will be shipped to Germany for certification. Satisfactory results were obtained with bus storage tanks, but there were welding problems with the car tanks and the results were less than optimal. It should be noted that the security engineering related to the infrastructures and the use of hydrogen for transportation purposes was subjected to HAZOP risk analyses and met the required standards.

The marketing of certain by-products is being planned for 1997. The new firm H2T, officially approved by the Québec cabinet in 1996, will be in charge of this facet. Lastly, it should be noted that the Euro-Québec/Hydro-Hydrogen project is funded in part by industry (45%) and by the Québec government and the Commission of the European Communities (55%).

Development of a membrane separation process for the treatment of waste acid

The manufacturing processes used by the metallurgical industry generate waste acids laden with heavy metals. The techniques used to treat these wastes entail high maintenance costs, generate classified sludge, require the transportation of dangerous goods, and exclude the possibility of recycling. Considering that some 700 million kilograms of waste need to be commercially treated in North America, it is vital to provide the industry with alternate ways of dealing with the problems inherent in current treatment processes.

LTEE and the Centre national en électrochimie et en technologies environnementales (CNETE) therefore initiated a project in 1992 aimed at developing an electrochemical membrane separation process for treating waste acid. This process consists of a modular technology which combines use of electrical energy and ion-exchange membranes, which are advanced synthetic filters that act as selective barriers in order to promote or inhibit the passage of particulate matter, molecules, or ionic species.

The work carried out to date has enabled researchers to demonstrate the many technical, economic and environmental advantages of the process compared with current techniques. For instance, tests have shown that by reducing metal content by 97%, the process becomes a highly efficient means of purifying sulphuric acid. Furthermore, depending on the initial acid content of the treated waste, the process allows the product to be reconcentrated by 25% to 50% and recycled at about 80%. Lastly, it was shown that even on a small scale, the process was economically viable and used little energy.

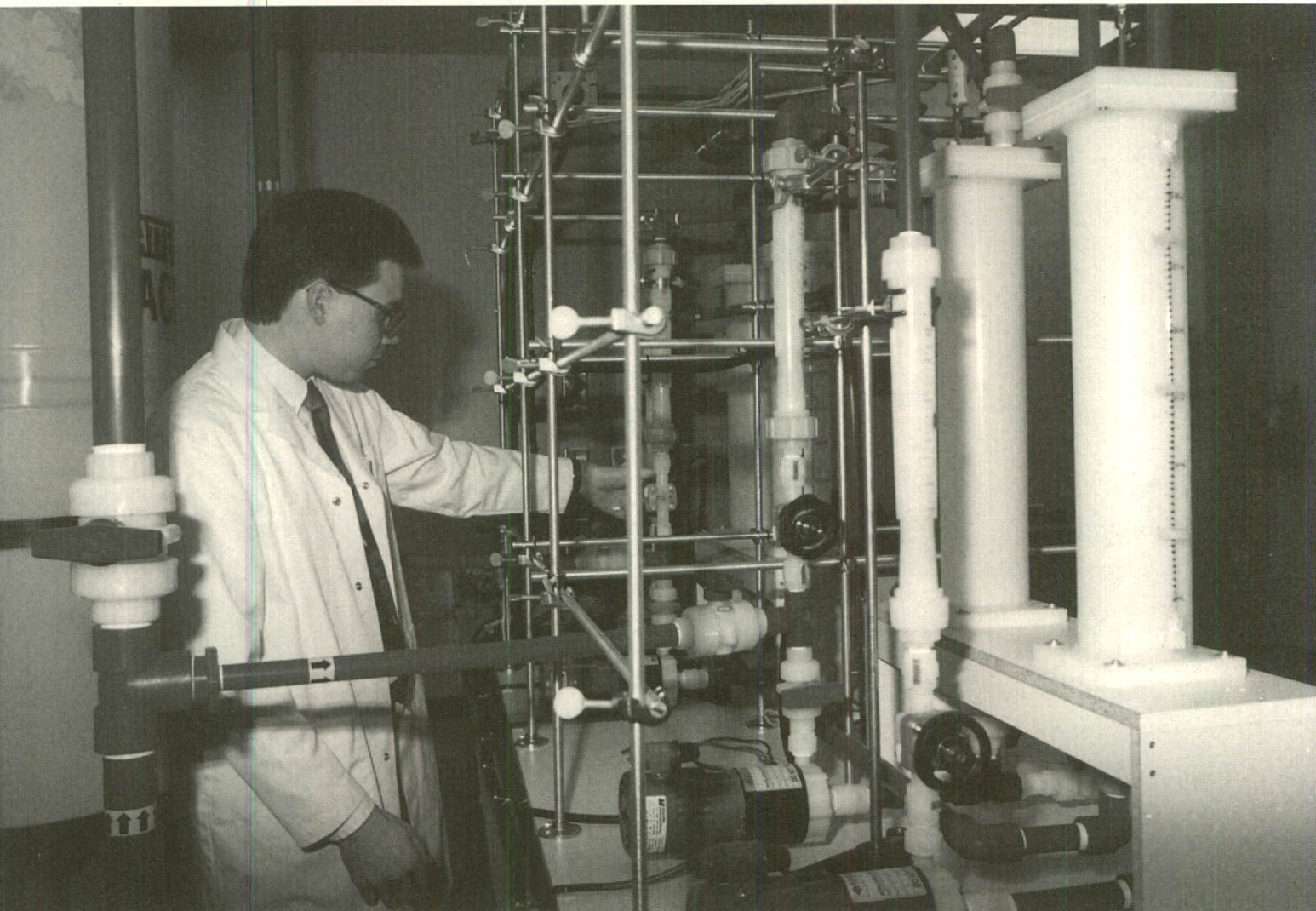
Diversification

In 1996, Hydro-Québec signed a major partnership agreement with the Belgian firm Solvay S.A. regarding the development and testing of new ion-exchange membrane prototypes for the treatment of waste acid contaminated with heavy metals. This agreement allowed researchers to complete the pre-industrial development of the process, which is scheduled to be part of a demonstration project under actual conditions in 1997. A marketing phase will also be undertaken, with the market potential ranging from \$800,000 to \$4 million.

Use of membrane separation for electrolyte purification

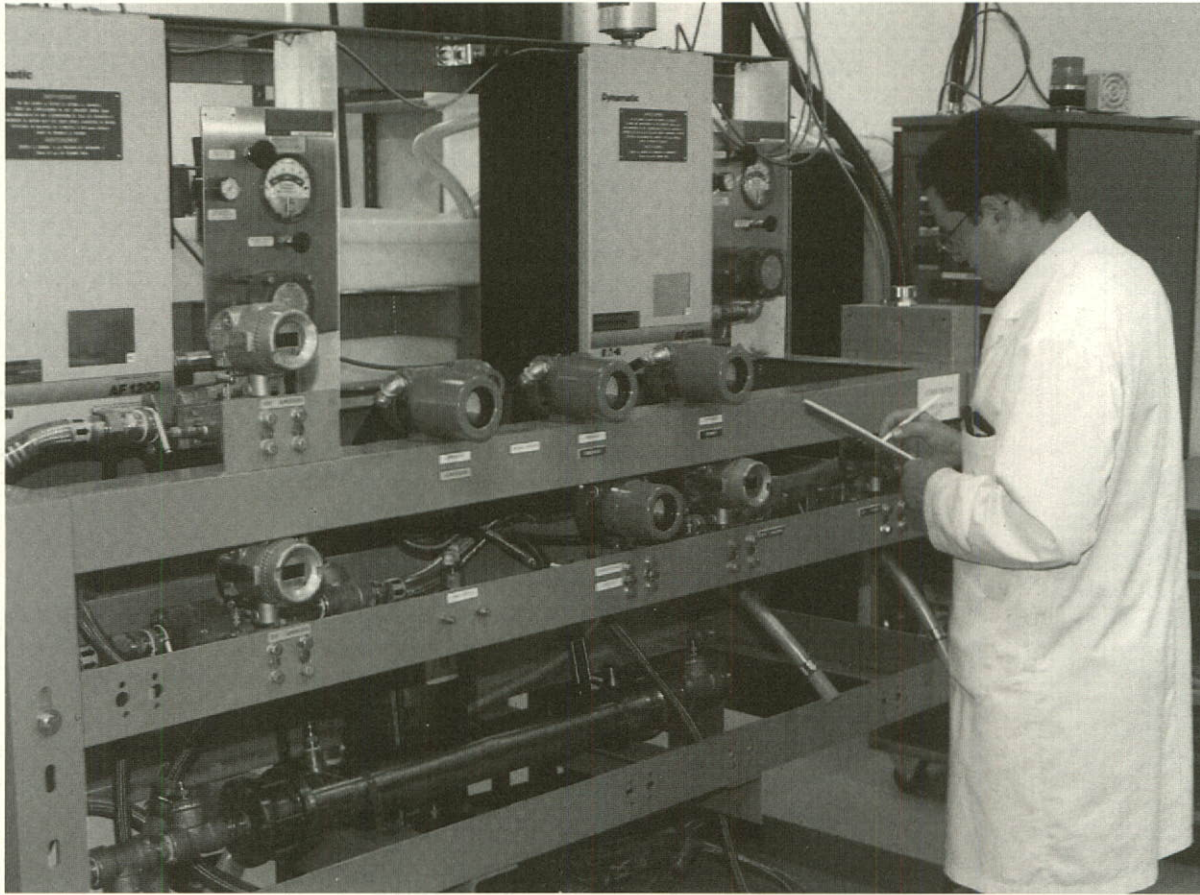
Hydro-Québec's electrochemical and electrical technology laboratory, LTEE, has developed a membrane separation technology to purify the electrolytes required for the production of sodium chlorate, a chemical used to bleach paper pulp and obtained through electrolysis using sodium chloride brine (electrolyte).

Installation used to study a membrane separation process for the treatment of waste acid.



Diversification

A process was developed for the purification of electrolytes used to produce sodium chlorate.



Studies have shown that the energy efficiency rating of electrolysis processes depends to a large extent on the purity of the electrolytes which supply the electrolytic cells. In fact, it is believed that the accumulation of impurities in the electrolytic circuits increases the consumption of energy required for the operation by 10%. Considering that about 30% of North American sodium chlorate is produced in Québec, it is vital for the industry to find ways of reducing impurities in order to minimize loss of energy efficiency.

In an effort to provide an efficient and cost-effective solution, LTEE joined forces with a major international chlorate manufacturer to initiate a project aimed at developing a physical separation technique, i.e. not requiring the

use of new chemicals, for electrolyte purification. In 1996, the process underwent extensive testing in actual operating conditions. The six-month test program corresponded to 1,500 hours of operation and confirmed the efficiency and economic viability of the new process.

Development of the process should be completed in 1997 with a view to subsequent marketing, which is currently being negotiated. Carried out for Hydro-Québec's chemical and paper industries department, the project also benefitted from active industry participation.

Appendix A

Other R&D projects

Generation

Borehole inspection method for concrete – Phases II and III
Cavitation in hydraulic turbines
Development and application of nanocrystalline materials for the storage of hydrogen
Development of repair methods and products for cracks in concrete structures
Device used to measure the electrochemical content of metals
Dielectric withstand of the epoxy insulation of generator windings based on parameters of manufacturing and use – Phase I
Dynamic load measurements – Analysis of fatigue and vibrations
Expert report on rotating-machine vibrations
Hydro-Québec International/Project in Lybia
Manufacturing of the SCOMPI II robot prototype
Opto-electronic detector for fish
Positioning robot
Robotized multipass welding
SCOMPI robot used for EDF's La Coche project
SUPER (continuous monitoring system for turbine-generators)
Support for the diagnosis of generating units
Underwater robot guiding
Use of high-content fly ash in grouts and shotcrete for hydraulic structures
Wind/diesel combination

Transmission

315-kV long-duration tests
500-kV tests on the Fujikura cable
Cracks in anchor bars
Development of a performance criterion for the dielectric withstand of 735-kV bushing shields
Development of analytical techniques for transformer oil
Electrical aging mechanism of EHV cables
Electrical behaviour of AC insulators under the effect of pollution
Electromagnetic behaviour – Telecommunications rooms
Environmental electromagnetic characterization – Transmission lines and various environments
Expert reports for the digital transmission system
Film/fluid (FF) insulation for high-voltage apparatus
Foundations of substation equipment
High-conductivity homogenous conductors
Impact measurement system
Impact of lightning on transmission lines and equipment
Inframetry and radiography of cable accessories
Installation of a monitoring system on six 1200-MVA short-circuit transformers
Line analysis software – Phase 2
Measurement of the grounded impedance under lightning conditions at the point of common coupling
Metering parameters and algorithms
Microphysical characterization of the insulation of 315-kV extruded cables
Modal analysis of power system behaviour
Monitoring and upgrading of MONITEQ systems installed at Lévis substation
Monitoring of the mechanical and electrical state of an 800-kV SF₆ double-pressure circuit breaker

Appendix A

Optimization of bolted electrical connectors
Rapid measurement of variables: pilot experiment on the power system
Real-time transient stability
Selection of a sensor for two types of circuit breakers
Sequence programmer
SERA (relay and automatic-control evaluation system)
Study of perception thresholds
Study on contaminants in insulating oils
Technological assessment of composite insulators for electrical apparatus
Testing of a sphere gap under conditions of fog and rain
Thermomechanical and microphysical characterization of 345-kV extruded cables
Thermomechanical behaviour
Universal measuring station

Distribution

Al/Cu service entrances exposed to salt air
Behaviour of D-type fuses under lightning conditions
Characterization of the dielectric behaviour of overhead transformers
Development of an improved Cu-W composite for disconnecting devices
Dynamic behaviour of partial discharges in the underground distribution system
Energy limit for submersible transformers
Evaluation of a remote-controlled mobile robot for underground distribution system maintenance
Measurement of the susceptibility of customer installations
Monitoring of pole hardness as a result of PCP-oil substitutes
Power quality measurement campaign – Phase I
Remote signalling of fault indicators
Self-protect fuse for open-link cutouts
Solid-state current-limiter circuit breaker
Study on the implementation and optimal operation of SF₆ technologies on the distribution system
Superconducting fault current limiter
Use of SMES (superconducting magnetic energy storage) in distribution – Phase I
Voltage analyzer
Voltage on the neutral of rural lines – Phase III

Utilization

Aminoanthraquinone (AAQ)
Cerium-based technology
Development of a process for producing chloride through transformation of lithium carbonate
Electrosynthesis III – Aromatic aldehydes
Magnetic materials for electric motors
Micro-SMES (superconducting magnetic energy storage) electrical leads
Modelling of pool heating
Naphtoquinone
PAQET (program aimed at improving the quality of thermal envelopes of buildings)
Use of nanocrystalline electrodes for chlorate

Appendix A

Diversification

Customer meters
Device for detecting electrical line faults
Electroanalytic measuring system
Validation of a switching plan for a substation or generating station diagram
Monitoring system technology
Motor-wheel project
Myco-Tech: a biological pesticide used to inhibit the growth of vegetation
Nucléo: process used for the decontamination of radioactive oil
Real-time power system simulators

Multi-purpose

Carbon electrocatalysis
Computer imaging
DÉGEL (engineering software and systems process)
Intelligent Power System project
Reflexe feasibility study
SATT project (technology transfer support system)
Superconducting materials
Telerobotic Development System – TDS project

Technical prospecting

Prospecting in analytical chemistry
Prospecting in cavitation-erosion
Prospecting in electrosynthesis
Prospecting in instrumental electrochemistry
Prospecting in welding
Technological prospecting in optical voltage transformers

Appendix B

Organizational Chart

Directeur principal, Recherche et Développement et directeur IREQ
General Manager Research and Development and Director IREQ
Roger Bérubé

Technologies de production
Generation Technology
Kinyoung Tea

Serge Mollicone, Appareillage de production et Mécanique

Generating Equipment and Mechanical Engineering

Guy Bélanger, Environnement et Chimie

Environment and Chemistry

Antoine Massad, Ouvrages civils et Matériaux

Civil Engineering Structures and Materials

Pierre Girard, Robotique

Robotics

Raymond Roberge, Technologies émergentes de production et de stockage

Emerging Generation and Storage Technologies

Technologies de transport et de distribution
Transmission and Distribution System Technology
Claude Parent

Yvan Chatigny, Appareillage électrique

Electrical Apparatus

Normand Bell, Lignes

Transmission Lines

Michel Manseau, Logiciels de réseaux

Power System Software

Roger Chahine, Logiciels de systèmes

Systems Software

Luc Audette, Systèmes d'automatismes et de mesure

Automatic Control and Measurement Systems

Technologies d'utilisation et LTEE
Application Technology and LTEE
Roger Bellemare

Réjean Girard, Applications industrielles

Industrial Applications

Denis Parent, Applications résidentielles, commerciales et institutionnelles

Residential, Commercial and Institutional Applications

Gaétan Lantagne, Procédés électrochimiques et métallurgiques

Electrochemical and Metallurgical Processes

Pierre Carignan, Support administratif et technique

Administrative and Technical Support

Appendix B

Laboratoires

Laboratories

Paul-Émile Vohl

Jacques Flamand, Laboratoire d'étalonnage et Réparation

Calibration Laboratory and Equipment Repair

Mario Paquin, Laboratoire Grande puissance

High-Power Laboratory

Normand Rivest, Laboratoire Haute tension

High-Voltage Laboratory

Claude Lacroix, Laboratoire mécanique et thermo-mécanique

Mechanical and Thermo-mechanical Laboratory

Michel Tétreault, Laboratoire Simulation de réseaux

Power System Simulation Laboratory

Germain Bissonnette, Maintenance et Montages d'essais G.P.

High-Power Maintenance and Test Assemblies

Jean Noiseux, Maintenance et Montages d'essais H.T.

High-Voltage Maintenance and Test Assemblies

Mario Tessier, Unités mobiles d'essais spéciaux

Special Testing Mobile Units

Développement de produits

Product Development

Yves Langhame

Robert Boulé, Développement multi-produits,

Multi-product Development

Bernard Laithier, Patrimoine et Partenariat technologiques,

Patents and Technological Partnerships

Michel Gauthier, Produits ACEP

ACEP Products

Norbert Major, Produits Appareillage, Matériaux et Procédés

Apparatus, Materials and Process Products

Pierre Mercier, Produits Appareils de mesure, Logiciels et Systèmes

Measuring Devices, Software and System Products

Germain Harbec, Produits M4

M4 Technology

Planification et Stratégies d'affaires

Business Planning and Strategies

André-Jean Filion

Daniel Brochu, Plans et Information de gestion

Plans and Management Information

Ressources humaines et Services

Human Resources and Services

Lise Bédard

Julien Martel, Atelier mécanique

Mechanical Workshop

Marc Tremblay, Communication et Documentation

Communications and Documentation

Jean-Roch Martin, Maintenance Site IREQ

Building Maintenance (IREQ)

Johanne Langevin, Services aux occupants

Building Services

Robert Michaud, Support informatique

Data Processing Support

Hydro-Québec

75, boul. René-Lévesque ouest
Montréal (Québec)
Canada H2Z 1A4
Telephone: (514) 289-2211
Fax: (514) 289-3674
Energy Info Line: 1 800 363-7443
E-mail: adcom@mail.dcrp.hydro.qc.ca

Institut de recherche d'Hydro-Québec (IREQ)

1800, boul. Lionel-Boulet
Varennnes (Québec)
Canada J3X 1S1
Telephone: (514) 652-8413
Fax: (514) 652-8161
E-mail: mfilion@ireq.ca

**Laboratoire des technologies électrochimiques
et des électrotechnologies (LTEE)**

600, rue de la Montagne
Shawinigan (Québec)
Canada G9N 6T6
Telephone: (819) 539-1400
Fax: (819) 539-1409
E-mail: donald@ltee.hydro.qc.ca

**Centre d'innovation en transport d'énergie
du Québec (CITEQ)**

1501, boul. Lionel-Boulet
Varennnes (Québec)
Canada J3X 1S1
Telephone: (514) 652-4651
Fax: (514) 652-4182
E-mail: msamson@citeq.hydro.qc.ca

Centre canadien de fusion magnétique (CCFM)

1804, boul. Lionel-Boulet
Varennnes (Québec)
Canada J3X 1S1
Telephone: (514) 652-8700
Fax: (514) 652-8625
E-mail: webmaster@ccfm.ireq.ca

Legal deposit - 2nd quarter 1997
Bibliothèque nationale du Québec
National Library of Canada
ISSN 1203-0880
ISBN 2-550-30224-9

Cette publication est également disponible en français.

Web site: <http://www.ireq.ca>

